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TRC Environmental Consultants, Inc.
Wethersfield, CT

Prepared for

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The objective of the Symposium was to provide a forum for the exchange of information among concerned representatives of industrial, research and governmental organizations relative to recent developments in industrial and energy-related fugitive emissions measurement and control.

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FOURTH SYMPOSIUM ON FUGITIVE EMISSIONS
Measurement and Control
(New Orleans, LA - May 1980)

Compiler

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FOREWORD

The technical papers included in this volume were prepared for presentation at the "Fourth Symposium on Fugitive Emissions: Measurement and Control," held in New Orleans, Louisiana on May 28-30, 1980.

The objective of the Symposium was to provide a forum for the exchange of information among concerned representatives of industrial, research and governmental organizations relative to recent developments in industrial and energy-related fugitive emissions measurement and control. The Symposium was sponsored by the Environmental Protection Agency's Industrial Environmental Research Laboratory at Research Triangle Park, North Carolina as part of its continuing effort to develop methods for the measurement and control of airborne and waterborne fugitive emissions.

D. Bruce Harris of the Industrial Environmental Research Laboratory was the Project Officer and the General Chairman of the Symposium.

Christine Wibberley of TRC-Environmental Consultants, Inc. was the Symposium Coordinator and Compiler of these Proceedings.

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This document has been reviewed by the U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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OVERVIEW OF FUGITIVE EMISSIONS

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May 1980

INTRODUCTION

Fugitive emissions comprise a major portion of the total national emissions for both Particulate Matter (PM) and Volatile Organic Compounds (VOC). There are 395 counties or parts of counties in nonattainment with the TSP National Ambient Air Quality Standard (NAAQS) and 538 in nonattainment of the ozone standard for which VOC is a major precursor. The EPA is currently reviewing the particulate matter standard; one possible outcome may be the regulation of particles smaller than 15 μm aerodynamic diameter, referred to as Inhalable Particulate (IP).

Several regulatory programs are concerned with fugitive emissions. State Implementation Plans require the control of PM and VOC to effect compliance with the NAAQS for Total Suspended Particulate and ozone. Regulatory programs, such as the Prevention of Significant Deterioration and regulatory policies such as the rural fugitive dust policy and the bubble policy are cognizant of fugitive emissions. The New Source Performance Standards are beginning to regulate fugitive emissions and many pollutants regulated under the National Emissions Standards for Hazardous Air Pollutants have fugitive emissions. Each of these will be discussed.

NATIONAL EMISSIONS ESTIMATES

Tables 1 and 2 give national emissions estimates for 1978 for particulate matter and Volatile Organic Compound (VOC) emissions. The total emissions are taken from background information for the National Air Pollutant Emissions Estimates - 1970-78.[1] Area source fugitive dust emissions from unpaved roads, entrainment of dust from paved roads, and unpaved airstrips based on 1977 National Emissions Data System (NEDS) data are also included.

The distinction between stack and fugitive emissions is based on a combination of published reports and engineering judgment.[2,3] Thus, the emissions should be considered as estimates only. The general criteria for defining stack or fugitive is as follows:

Stack emissions include

- Process and fuel combustion sources vented directly through a stack.
- Processes vented through cyclones or bag filters considered to be an integral part of the process.
- Processes vented through stacks serving exhaust or ventilation system normally associated with a process for safety and health purposes.
- Process vents with defined airflow sufficient to resemble stack exhaust.
- Exhaust emissions from mobile combustion sources.

Fugitive emissions include

- Open sources with no stack or associated ventilation system.
- Storage vessels.
- Material handling and transfer losses not normally collected by cyclones or bag filters as an integral part of the process.
- Leaks in process equipment.
- Evaporative emissions not collected and vented through an exhaust hood and ventilation system.
- Dust entrainment by motor vehicles.
- Evaporative emissions from motor vehicle fuel tanks/crankcases.
- Wind erosion of open storage piles.

Fugitives are shown in Table 1 to account for 90 percent of total particulate emissions. Major categories include resuspended dust from highway vehicles, burning of trash and agricultural land, forest and structural fires, and industrial processes. Industrial fugitives account for 70 percent of all industrial emissions with the major sources being iron and steel, primary copper, cement, crushed stone, brick manufacturing, coal strip mining, and grain elevators.

Table 2 gives a national estimate of VOC emissions. Total VOC emissions are about 40 percent from fugitives, with the major source categories being transportation, burning, solvent use, and industrial processes from petrochemicals, crude and gasoline storage and transfer, degreasing, dry cleaning and surface coating.

Controls of fugitive sources are usually tailored to the specific situation. Typical control techniques include containment and control, surface treatment, improved seals and equipment design, modified operating practices and in some cases changing the process itself. Table 3 summarizes typical control techniques for various fugitive sources. Several novel techniques being explored are road carpet as an underlayment for unpaved roads and a charged droplet fog spray for treating either confined or unconfined plumes.

AIR QUALITY IMPACT OF MAJOR FUGITIVE SOURCES

Volatile organic compounds affect the amount of ozone in the air. These VOC provide a means of converting ambient nitric oxide (NO) to nitrogen dioxide (NO_2) which does not consume ambient ozone (O_3). Subsequently, the resulting NO_2 reacts with sunlight to form O_3. The net result of these chemical reactions is a buildup in ambient levels of ozone. The resulting high concentrations of ozone tend to occur on an urban or regional scale.

Many studies which interpret particulate air quality and emissions data to estimate source contributions can give some indication of the source contributions as stack versus fugitive. An example of this would be studies using optical microscopic analysis of hi-volume sampler filters. Table 4 summarizes the results of the analysis of 300 filters from 14 U.S. cities.[4] Using the component categories defined by the microscopist, it is possible to make a rough estimate of the fugitive source contributions to ambient air. First, assume that mineral matter comes mostly from windblown and mechanically induced fugitive dust sources and that rubber and paper come primarily from vehicle resuspension of tire particles and litter. Also, assume that fugitive windblown dust from coal storage piles, iron and steel fugitive sources and starch from grain handling contributes in part to particulate ascribed to these categories. It can then be seen that fugitive dust and emissions contribute perhaps from 50-90+% of ambient TSP concentrations.

Fugitive particulate emissions differ from most stack emissions in three respects: 1) most of the emissions are larger particles and tend to settle out relatively near the source; 2) the emissions are usually emitted at or near ground level; and 3) emissions generally are at or near ambient temperature and undergo little thermal plume rise. These differences result in a large gradient in ambient concentrations decreasing with distance from the source. This has been demonstrated both with modeling studies and with ambient monitoring studies.[5,6] The following is a brief discussion of the ambient impact of selected sources.

Unpaved Roads. The Lincoln-Lancaster County (Nebraska) Health Department and the EPA performed a study of short term ambient concentrations around an unpaved road in Lincoln, Nebraska.[7,8] For a one hour period, the traffic on a road in a rural area southwest of Lincoln was increased to over 100 vehicles per hour. Hi-volume samplers and dichotomous samplers were located at distances of 10, 30 and 50 meters from the roadside.

Typical concentrations were very high because short term measurements were taken under peak traffic conditions. Hi-vol readings were several thousand $\mu g/m^3$, and typical dichotomous sampler readings were in the low hundreds ($\mu g/m^3$) range. The concentrations at the 30 and 50 meter distances are plotted in Figure 1 as a fraction of the 10 meter hi-vol concentration. It can be seen that the hi-vol concentration is reduced substantially at 30 and 50 meters, but little decrease is seen in the dichotomous data which measures only those particles smaller than 15 μm. This suggests that many of the larger particles are settling to the ground very close to the source.

Paved Road Sources. Data have been collected at many locations which suggest a high particulate matter concentration around paved roads. Studies in Boston,[9] Kansas City[10] and Hamilton, Ontario[11] all show these high concentrations which decrease rapidly within 75 meters of the road. An empirical study of data at 79 sites found a relationship between average daily traffic (ADT), height of the monitor (HGT) and distance from the road (DIS):

$$\text{concentration} \sim \frac{\ln \text{ADT}}{\sqrt{\text{HGT}^2 + \text{DIS}^2}}$$

Typically, a paved road might contribute an average of 15-25 $\mu g/m^3$ at sites located only 4 meters from a typical heavily travelled paved road.[5] Current EPA monitor siting guidance suggests that monitors be located outside of this zone of direct influence. Typically, a monitor might be placed at least 25 meters away from a road and the contribution of that road would probably be less than 5 $\mu g/m^3$ at that point. This contribution can be much higher if the road were particularly dusty or dirty.

Industrial Sources. Many industrial sources have been sampled by upwind-downwind ambient techniques to estimate the emission factors for processes. One recent study was conducted by the National Crushed Stone Association to estimate emissions from construction aggregate crushing operations. Table 5 summarizes the results of instantaneous ambient measurements of particles smaller than 10 μm at a distance of 30 feet downwind of uncontrolled crushing operations. The table shows that significant dust levels are found just downwind of these operations. One would not expect fenceline concentrations to be this great.[12] However, one would expect much higher concentrations if particles larger than 10 μm were included in the study.

EMISSION MEASUREMENTS

Two new measurement methods are being considered for proposal along with the New Source Performance Standards (NSPS) for the Synthetic Organic Chemical Manufacturing Industries (SOCMI) and Metallic Minerals industries.

Method 21 applies to the determination of volatile organic compound leaks from organic process equipment. Specifications and performance criteria for a portable instrument will be specified under this method. Method 22 is concerned with documenting the presence and duration of visible plumes from various particulate fugitive emission sources. It will specify such parameters and how the emissions are to be observed and recorded.[13]

Several of the more established methods for measuring fugitive particulate emissions are being documented in a sampling protocol.[14] These methods include roof monitor, quasi stack, upwind downwind and exposure profiling. These methods are being employed in a major research effort to determine emission factors for particulate matter. The program, being coordinated by the EPA's Industrial Environmental Research Laboratory, is a major program measuring particulate emissions by particle size from the major stack fugitive source categories. New instruments being used in this program include a size selective inlet for the high volume sampler for use in upwind/downwind sampling and a horizontal elutriator which will be used in conjunction with the roof monitor method. A new sampling train for IP has been developed which uses cyclones to provide data for 15 μm particles.

REGULATORY PROGRAMS

New Source Performance Standards (NSPS) and National Emissions Standards for Hazardous Air Pollutants (NESHAPS) are beginning to address fugitive organic and particulate sources. Fugitive emissions are of concern in both TSP and ozone State Implementation Plans (SIP's). Also, programs such as the bubble policy and PSD are affected by fugitive emissions.

NSPS for Particulate Matter -- Basic industrial process fugitive emission sources have been addressed in prior NSPS. These include such operations as material transfer, crushing, grinding, process equipment leaks, etc. Examples of this include the NSPS for lime plants, asphalt concrete plants, copper, lead and zinc smelters, coke ovens and grain elevators. Only recently, however, have the emissions from windblown and vehicle entrained particulate sources been mentioned in connection with NSPS. The upcoming NSPS for the metallic minerals industries and gypsum plants may include provisions for storage piles, tailing piles, and haul road emissions within and near the plant boundary.

A new concept is being considered in developing a NSPS for metallic minerals. This is the proposal of Method 22 for visible emissions, as mentioned earlier. This method will provide for documenting the duration of a visible plume from specific process points or operations. NSPS regulations in the future may specify the percentage of time that specific processes must be void of visible emissions.[13]

NSPS for Volatile Organic Compounds (VOC) -- New Source Performance Standards for VOC are beginning to consider fugitive emissions. Two main categories of sources, petroleum refining and Synthetic Organic Chemical Manufacturing Plants (SOCMI) are being considered for control of leakage from pumps, valves, flanges, compressors and cooling towers. Regulation may require specific hardware such as double mechanical seals for pumps, or intermittent monitoring with portable hydrocarbon monitoring devices for such sources as valves and flanges. This could be a significant consideration since the SOCMI produces 350 to 400 basic chemicals at facilities which contain almost 50,000 pumps, 800,000 values and 1.8 million flanges. Other types of sources such as storage tanks for volatile organic liquids may follow the recently promulgated Petroleum Storage Tank NSPS and require floating roofs.[15],[16]

A third major category of VOC fugitive emissions is the coatings industry. Eight new NSPS are being developed now with seven of these scheduled for proposal this year. Regulation will probably be based on the emissions allowable per volume of solids applied. Controls may be through increasing the solids/solvent ratio, collection by solvent recovery systems, such as carbon adsorption, or by incineration.[17]

NESHAPS -- Section 112 of the Clean Air Act, as amended in 1977, requires the establishment of emission standards for hazardous air pollutants. Six pollutants have already been listed and NESHAPS have been, or are currently being established. These pollutants are: mercury, beryllium, asbestos, vinyl chloride, benzene, and radionuclides. Nine other compounds or elements are currently being considered for listing as hazardous pollutants; these are listed in Table 6. Of these, arsenic, polycyclic organic matter, perchloroetylene, tricholoethylene, acrylonitrile, and cadmium seem to have a higher probability of being listed.[18]

Fugitive emissions may be a concern with all of these compounds. Certainly, arsenic sources have been identified as major contributors of fugitive emissions and POM's are associated with coking operations. Acrylonitrile storage tanks are a source of fugitive emissions.[19] Cadmium has not yet been assessed by the EPA for fugitive emissions.

TSP SIP -- Generally, States in nonattainment areas are expected to regulate industrial process fugitive particulate emissions. However, the policy for urban fugitive dust emissions is less clear. The EPA and the States/locals are planning a series of demonstration studies to evaluate the effectiveness of controls on a small scale. Some of these studies are listed in Table 7. Originally, it was thought that many other areas would be proposing demonstration studies at this time. However, many of these are delayed pending a more complete understanding of the ambient contribution of urban fugitive dust sources in various particle size ranges of interest.[20]

Ozone SIP -- The 1979 ozone SIP's generally called for the States to adopt regulations for a certain group of hydrocarbon sources (Group I). These included the coil, can and paper coating industries, degreasing and gasoline marketing. These regulations must be equivalent in stringency to the levels specified in the control techniques documents for these sources. The States must also commit to adopt regulations for a second set (Group II) of sources. Such sources include petroleum refinery fugitive emissions, miscellaneous metals coatings, flatwood paneling, graphic arts, synthesized pharmaceutical products, tire manufacture, perchoroethylene dry cleaners, gasoline tanker trucks, vegetable oil manufacture, and petroleum liquid storage in external floating roof tanks.[20,21] All of these sources have a significant part of their emissions from fugitive sources.

Bubble Policy -- The EPA adopted a new "bubble" concept to consider the control of certain in-plant fugitive sources in lieu of placing additional control on certain stack emissions within a given facility. Where a source wishes to trade open source dust controls for the more significant sources of process emissions, the bubble policy allows sources to demonstrate the equivalency of such trades by installing the open source controls and then monitoring the results.[22]

Prevention of Significant Deterioration -- In the past, fugitive emissions, as well as point or stack emissions, were used in determining if a source were large enough to be covered by PSD regulations. As a result of a recent court suit brought by Alabama Power and Light, (AP&L) and other plaintiffs, the EPA is undertaking special rulemaking to define the manner in which fugitive emissions from certain source categories are considered. Fugitive emissions will still be used in calculating the increment consumed by a source, since this was not affected by the AP&L case. However, until the rulemaking is complete, potential emissions are being calculated from stack emissions only for purposes of determing if a source is subject to PSD.[22]

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TABLE 1. Estimate of Particulate Matter Emissions (10^3 tons/yr)

Source Category	Stack Emissions	Fugitive Emissions
Transportation	884	395 (5354)
Highway Vehicles	537	395 (4950)[1]
LDV	308	257
LDT	57	48
HDG	75	25
MC	4	0
HDD	93	65
Railroads	69	0
Aircraft	82	(9)[2]
Vessels	28	0
Misc. off-highway-gasoline	16	0
Misc. off-highway-diesel	152	0
Stationary Fuel Combustion	4150	0
Industrial Processes	2097	4666
Iron and steel	225	690[3]
Primary aluminum	67	39
Primary copper	35	322[3]
Primary lead	4	37[3]
Primary zinc	1	20[3]
Ferroalloys	39	19
Gray iron foundries	30	123
Secondary non-ferrous metals	68	12
Chemicals	189	19
Cement	80	781
Sand and gravel	0	47
Crushed stone	0	1478
Phosphate rock	16	30
Brick and clays	185	296
Lime	116	48
Glass	29	0
Asphalt batching	127	36
Concrete batching	18	92
Coal cleaning	15	0
Coal strip mining	0	195
Gypsum	66	1
Asphalt Roofing	8	0
Pulp mills	263	0
Plywood	26	0
Cotton ginning	13	0
Grain elevators	395	349
Food and grain mills	1	7
Cattle feed lots	0	25
Petroleum refining	81	0
Solid Waste	219	256
Incinerators	219	0
Open burning	0	256
Miscellaneous	0	735 (38,735)
Forest Fires	0	574
Agricultural Burning	0	92
Structural fires	0	69
Unpaved road vehicle travel	0	(38,000)[4]
TOTAL	7350	6052 (49,011)

[1] NEDS area source total shown in parentheses represents entrainment of dust from paved roads. Tranportation fugitive total also includes tire wear.

[2] NFDS area source total for unpaved airstrips.

[3] Includes ore mining emissions all assumed to be fugitive.

[4] NEDS area source total for unpaved roads. Other totals shown in parentheses include this total.

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TABLE 2. Estimate of National VOC Emissions (10^3 tons/yr)

Source Category	Stack Emissions	Fugitive Emissions
Transportation	8459	3266
Highway Vehicles[1]	7035	3167
LDV	4257	2327
LDT	1038	577
HDG	1356	227
MC	174	36
HDD	210	0
Railroads	188	0
Aircraft	227	0
Vessels	476	0
Misc. off-highway-gasoline[1],[2]	361	99
Misc. off-highway-diesel[3]	172	0
Stationary fuel combustion	326	0
Industrial Processes	8640	6322
Petroleum refining	617	343[4]
Petrochemicals[11]	758	1112[5]
Crude oil and natural gas production	0	256[6]
Crude oil and gasoline storage tanks[7]	0	627
Gasoline bulk terminals/plants[8]	0	615
Gasoline service stations[9]	0	1082
Gasoline/crude oil transfer[10]	0	572
Plastics	374	0
Other Chemicals[11]	583	0
Adhesives	254	28
Coke	0	49
Fermentation	0	90
Vegetable oil	21	0
Bakeries	46	0
Glass	2	64
Dry cleaning	100	258
Degreasing	0	571
Graphic arts[12]	348	39
Surface coating[13]	2304	256
Misc. organic solvent[14]	3060	340
Other processes[14]	173	19
Solid Waste Disposal	380	480
Incineration	380	0
Open burning	0	480
Miscellaneous	0	2815
Forest fires	0	642
Agricultural burning	0	85
Structural fires	0	47
Architectural coating	0	331
Cutback asphalt paving	0	686
Miscellaneous solvent use	0	1024
TOTAL	17,805	12,883

[1] Based on classification of exhaust emissions as stack emissions and evaporative/crankcase emissions as fugitive emissions

[2] Includes farm, construction, industrial engines, snowmobiles, lawn and garden tractors, and off-highway motorcycles.

[3] Includes farm, construction, industrial engines.

[4] Includes emissions from process drains, cooling towers, asphalt blowing, valves and seal leaks, sampling, etc.

[5] Assume estimated emissions from storage and handling losses, and other fugitive sources as fugitive emissions.

[6] Assumed all fugitive stack emissions from fuel combustion equipment included under stationary fuel combustion.

[7] Includes tanks at oil fields and refineries only.

[8] Storage tanks only.

[9] Stage I and Stage II.

[10] Includes ship and barge transfer and filling, rail and truck tankers.

[11] Petrochemicals include all products in SIC 2865, 2869. Other chemicals include other organic and inorganic chemicals.

[12] Assumes that solvent vapors are collected by an exhaust system and vented through a stack. It is assumed that 10% of emissions are fugitive, escaping the exhaust system or carried out with products and evaporated later (allowance).

[13] Assumes emissions occur from spray booths and baking ovens vented to stacks. Evaporative emissions from flash-off of solvent are assumed to be 10% of total emissions (allowance).

[14] Assumed to be predominantly stack emissions, allowance 10% of total emissions reported as fugitive.

TABLE 3

TYPICAL CONTROL TECHNIQUES FOR VARIOUS FUGITIVE SOURCES

OPEN SOURCES	VARIOUS (FOGGERS, WATERING, OPERATING PRACTICE)
STORAGE VESSELS	FLOATING ROOFS/SEALS, VAPOR COLLECTION/RECOVERY
MATERIAL HANDLING AND TRANSFER	CONTAINMENT, WATER SPRAYS, FOGGERS
LEAKS IN PROCESS EQUIPMENT	IMPROVED SEALS/EQUIPMENT DESIGN, ROUTINE INSPECTIONS IMPROVED MAINTENANCE/OPERATING PRACTICES
PROCESS EVAPORATIVES	VAPOR COLLECTION/RECOVERY, SOLVENT SUBSTITUTION, SOLIDS - SOLVENT RATIO
VEHICLE DUST ENTRAINMENT	PAVED - STREET CLEANING, DEPOSITION CONTROLS UNPAVED - PAVING, CHEMICAL STABILIZATION, ROAD CARPET
VEHICLE EVAPORATIVES	PCV, CONTAINMENT
WIND EROSION	PILE CONTOURING, WIND BREAKS, CONTAINMENT, WATERING, CHEMICAL STABILIZATION

TABLE 4

U.S. COMPOSITE SUMMARY OF FILTER ANALYSES

COMPONENTS	QUANTITY, percent	
	AVERAGE	RANGE
MINERALS	(65)	3-99
* QUARTZ	29	1-84
* CALCITE	21	1-93
* FELDSPARS	5	0-35
* HEMATITE	10	0-65
* MICA	1	0-15
OTHER	1	0-46
COMBUSTION PRODUCTS	(25)	1-89
SOOT:		
OIL	7	0-86
* COAL	5	0-52
MISC. SOOT	5	0-88
GLASSY FLY ASH	6	0-30
INCINERATORY FLY ASH	2	0 45
OTHER	1	0-19
BIOLOGICAL MATERIAL	(3)	0-90
POLLEN	1	0-45
SPORES	1	0-2
* PAPER	1	0-3
* STARCH	1	0-10
MISC. PLANT TISSUE	1	0-8
LEAF TRICHOMER	1	0-18
MISCELLANEOUS	(7)	0-50
* IRON OR STEEL	1	0-25
* RUBBER	7	0-50
OTHER	1	0-15

TABLE 5

MEAN DUST CONCENTRATIONS FOR PARTICLES SMALLER THAN 10 μm MEASURED 30 FEET DOWNWIND

PLANT	STONE TYPE	PRIMARY CRUSHER	SECONDARY CRUSHER	TERTIARY CRUSHER	FINES CRUSHER
A	GRANITE	200 ± 85[a]	350 ± 210	1140 ± 740	1600 ± 290
B	SAND & GRAVEL	130 ± 170	440 ± 390		
C	SAND & GRAVEL	170 ± 140	570 ± 200		
D	TRAPROCK	640 ± 590	930 ± 640	210 ± 290	410 ± 280
E	LIMESTONE		68 ± 43[b]		
F	LIMESTONE		170 ± 640		
G	LIMESTONE		2200 ± 1000	810 ± 450	

[a] (STANDARD DEVIATION)

[b] WET PROCESS

TABLE 6. Compounds Currently Being Considered for Listing as Hazardous Pollutants[a]

Arsenic

Polycyclic Organic Matter

Perchlorethylene

Trichloroethylene

Acrylonitrile

Cadmium

Methyl Chloroform

Methylene Chloride

Toluene

[a] Compounds listed first have a higher probability of being listed.

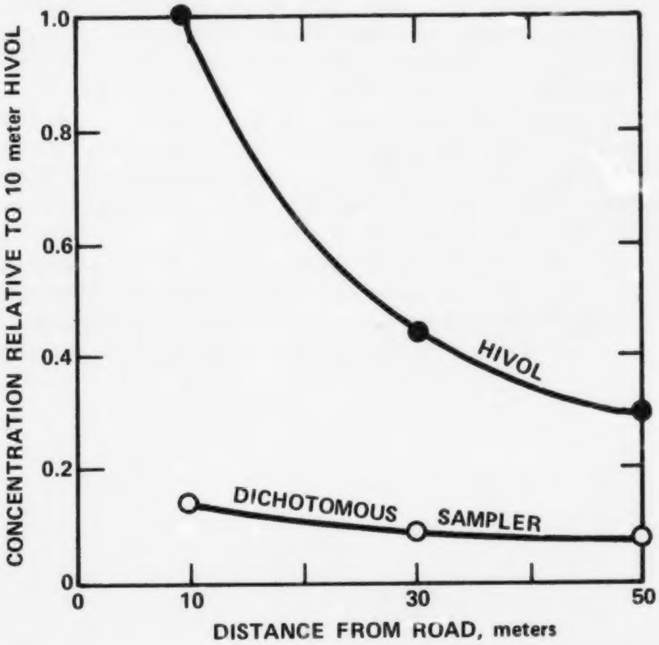
TABLE 7

DEMONSTRATION STUDIES PLANNED BY STATES AND THE EPA TO EVAULATE CONTROLS FOR FUGITIVE DUST SOURCES

STUDY	CONTROLS EVALUATED
PORTLAND, OREGON	VACUUM SWEEPING OF PAVED STREETS IN INDUSTRIAL AREA
DENVER, COLORADO	REDUCE FUGITIVE DUST DUE TO SANDING FOR SNOW CONTROL
MINNEAPOLIS, MINNESOTA	CONSTRUCTION GENERATED DUST - ESPECIALLY MUD CARRYOUT
LAS VEGAS, NEVADA	PAVING OF GRAVEL ROADS AND MODIFY SUBDIVISION CONSTRUCTION PRACTICES
TUCSON, ARIZONA	CONTROL OF TAILINGS PILES AND UNPAVED ROADS

FIGURE 1

RELATIVE SHORT TERM CONCENTRATIONS MEASURED BY DICHOTOMOUS SAMPLERS AND HI-VOLS AT DISTANCES OF 10, 30 AND 50 METERS FROM AN UNPAVED ROAD



FUGITIVE EMISSIONS CONTROL AFTER ALABAMA POWER

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ABSTRACT

Recent studies indicate that traditional stack-oriented control strategies for particulate matter are insufficient by themselves to achieve the ambitious air quality goals of the Clean Air Act. Control of industrial fugitive emissions and nontraditional sources of fugitive dust will therefore be an essential ingredient in future control strategies for particulate matter. Control of new, and possibly existing, fugitive emission sources will also be required in order to comply with EPA's regulations on Prevention of Significant Deterioration (PSD). This paper attempts to summarize the federal regulations and policies applicable to fugitive particulate matter sources under the Clean Air Act. Pertinent provisions of EPA's regulations and guidelines for nonattainment and PSD areas are discussed. Particular emphasis is given to discussing the impact of the recent Alabama Power decision and EPA's proposed regulations of September 5, 1979 dealing with PSD and nonattainment new source review.

INTRODUCTION

On June 18, 1979, the United States Court of Appeals for the District of Columbia issued its initial ruling in the case of Alabama Power Company v. Costle.[1] This decision made substantial changes to EPA's regulations for preventing significant deterioration (PSD) of clean air. Due to the close relationship between the PSD program and EPA's regulations for nonattainment areas, the Alabama Power decision will affect both sets of regulations.

The issues addressed in Alabama Power cover the full spectrum of the PSD regulations promulgated by EPA in mid-1978. The decision directly dealt with how fugitive emissions may be regulated under the Clean Air Act and with EPA's fugitive dust exemption. Perhaps more importantly, through its broad discussion of what sources and modifications are subject to review, which pollutants must be considered, and how geographic location affects the type of review, the Court indirectly made fugitive emissions the subject for increased regulation in the future.

OVERVIEW OF DEVELOPMENTS SINCE THE CLEAR AIR ACT AMENDMENTS OF 1977

The 1977 Amendments to the Clean Air Act were the foundation for today's PSD and nonattainment new source review program. The 1977 Amendments gave rise to EPA's 1978 PSD regulation which, in turn, directly lead to the court challenge resulting in Alabama Power. Alabama Power, both directly and indirectly, will force major substantive changes in EPA's regulation of fugitive emissions and to EPA's PSD and nonattainment new source review program. Thus, it is useful to understand these post-1977 developments.

Nonattainment

The widespread failure of many of the nation's air quality control regions (AQCR's) to attain the National Ambient Air Act Standards (NAAQS) by the original July 1, 1975 deadline created a dilemma concerning the legal approvability of new sources which would add to levels of pollution already in violation of the law.

EPA responded to this problem with promulgation of its national Offset Policy on December 21, 1976.[2] The essence of the Offset Policy was that major new growth should be allowed in nonattainment areas only if air quality is improved as a result of the growth. This improvement comes by way of contemporaneous emission reductions from existing sources so as to more than "offset" the emissions which will be added by the proposed new source.

The Offset Policy imposed four substantial conditions on major new or modified sources, including major sources of fugitive dust, seeking permits to expand in and around nonattainment areas. First, the source must reduce its emissions to the lowest achievable emission rate (LAER). Second, it must be able to certify that all sources which it owns or controls in the same state are either in compliance or on a schedule of compliance with the State Implementation Plan. Third, the new source must obtain emission reductions from existing area sources which more than "offset" the pollution to be added by the new LAER-controlled source. These offsetting emission reductions must exceed the proposed new emissions by enough to represent "reasonable further progress" toward attainment of the ambient standards. The fourth and final condition, closely related to the third, requires the owner to demonstrate that the combination of LAER and offsets will lead to a net air quality benefit in the affected area.

Congress met the nonattainment issue head-on in the 1977 Clean Air Act Amendments by continuing the Offset Policy until mid-1979 and establishing a State Implementation Plan (SIP) revision process to deal with the problem after that date. Specifically, section 129 of the 1977 Amendments provided that EPA's Offset Ruling, as it may be amended, was to remain in effect, except that the baseline for determining emission offset credit was changed and the source applicability was expanded. By January 1, 1979, the States were to have submitted plan revisions to EPA which conform to new Part D of the Act. These revised plans are designed to replace EPA's Offset Policy and were to have been approved by no later than June 30, 1979. Failure to adopt and receive EPA approval of the revised plan by this deadline triggers a statutory ban on major new sources (of the nonattaining pollutant) in the nonattainment area. Many states have incorporated elements of the Offset Policy into their SIP.

Table I summarizes the development of the nonattainment provisions and the Offset Policy.

Prevention of Significant Deterioration

While the objective of the nonattainment provision is to achieve and maintain the ambient standards, the purpose of PSD is to prevent significant deterioration of air already cleaner than the ambient standards.

The PSD controversy began as a result of a seemingly unimportant phrase in the original law stating that one of the Act's four basic purposes was to "protect and enhance" the quality of the nation's air. Relying primarily upon this provision environmental groups brought suit against EPA on May 24, 1972, to prevent the agency from approving state plans which did not prevent significant deterioration of clean air.

This challenge was ultimately successful, and on December 5, 1974, EPA promulgated regulations to prevent emissions of sulfur dioxide and particulate matter from significantly deteriorating air quality in areas where concentrations of those pollutants were lower than the applicable national ambient standards.[3] EPA incorporated its PSD regulations into the implementation plan of each state pursuant to Section 110(c) of the Act and established a procedure by which EPA could delegate its PSD responsibility to states.

TABLE I

CHRONOLOGICAL DEVELOPMENT OF EPA'S OFFSET POLICY AND THE ACT'S NONATTAINMENT PROVISIONS

Original Deadline for Attaining the Primary NAAQS
7/1/75

Promulgation of EPA's Offset Policy
12/21/76

The 1977 Clean Air Act Amendments
8/7/77

EPA Administrator's Memorandum Detailing the Criteria
for Approving SIP Revisions for Nonattainment Areas
2/24/78

EPA Promulgates List Designating PSD and Nonattainment
Areas Pursuant to Section 107 of the Act
3/3/78

Revised SIPs Due to EPA
1/1/79

EPA Promulgates Major Revisions to Its Offset Ruling
1/16/79

Initial Ruling in *Alabama Power vs. Costle*
6/18/79

Deadline for EPA Approval of the Revised SIP
(Failure to Obtain Approval by Deadline Triggers the
Growth Ban Provision of Section 110(a)(2)(I))
6/30/79

EPA Proposes Revisions to PSD and Nonattainment Rules
9/5/79

EPA Publishes Final Revisions to PSD and Nonattainment Rules
6/80

New Deadline for Attaining the Primary NAAQS
12/31/82

Extended NAAQS Deadline for Areas Unable to
Attain the Oxidant and/or Carbon Monoxide Standards
12/31/87

The regulations prohibited construction of stationary sources in any of 19 specified categories unless EPA (or a delegated state) had issued a permit evidencing that the source would apply "best available control technology" (BACT) for sulfur dioxide and particulate matter and that emissions of those pollutants would not cause significant deterioration of clean air. For determining what levels of deterioration were "significant," the regulations set out an area classification system. Under that system, clean air areas could be classified as Class I, II, or III. In Class I areas, small increases of sulfur dioxide and particulate matter would be significant. In Class II areas, moderate increases were allowed, and in Class III areas, increases were permissible up to an ambient standard. The regulations initially classified all PSD areas as Class II, but gave states, Indian governing bodies, and federal land managers the opportunity to reclassify their lands under specified procedures.

The 1977 Amendments affirmed EPA's development of the PSD concept.[3a] The new statutory scheme follows the outline of the pre-existing regulations,[4] but is generally more comprehensive and restrictive. Some of the more significant changes introduced by the 1977 Amendments include:

- Formal Designation of PSD Areas - Under Section 107(d) of the new Act, all areas with air quality better than the national standards (or of indeterminate status) must be formually listed by EPA. EPA issued this list on March 3, 1978.[5] Several revisions have been made since March 3, 1978.[6]

- More Restrictive "Increments" - The new law reduces the allowable short-term increments for SO_2 and particulates in Class II and III areas. Class I increments remain the same.[7]

- New Mandatory Class I Areas - The new Act retains the 3-class concept of the original PSD regulations and affirms the automatic Class II designation for most PSD areas. However, large national parks above a certain size which were in existence when the Amendments were enacted (8/7/77) are now designated as mandatory Class I areas. These areas may not be redesignated.[8]

- More and Different Sources Subject to PSD Review - The new Act increases the number of source categories subject to PSD preconstruction review from 19 to 28. New and modified sources within one of these 28 categories are subject to PSD if they have the potential to emit or increase emissions by 100 tons per year of any pollutant regulated under the Act. Furthermore, all new or modified sources, regardless of their category, are covered if they have the potential to emit 250 tons or more per year of any regulated pollutant.[9] Major sources of fugitive dust were covered by the 250 ton criteria.

- More Restrictive Definition of BACT - Under the original PSD regulations, Best Available Control Technology (BACT) could not be more restrictive than the New Source Performance Standards (NSPS) applicable to the source category being proposed. Where NSPS had not yet been established for the applicable category, BACT was a case by case determination which weighed economic, technology, energy and geographic factors. Under the new law, BACT is always a case by case determination. Where New Source Performance Standards (or hazardous emission standards) apply to the proposed source, they represent a minimum, rather than a maximum, level of required control. More importantly, BACT now applies to all pollutants regulated under the Act, not just SO_2 and particulate matter as under the prior regulations.[10]

- Substantially Increased Monitoring and Modeling Requirements - Under the original PSD Regulations, applicants merely had to demonstrate, through atmospheric diffusion modeling, that the proposed emissions would not violate the allowable increments. The new law imposes far more sophisticated modeling requirements. In addition, air quality and meteorologic monitoring requirements may now be required both prior to and after construction.[11]

- Other Criteria Pollutants to be Regulated in the Future - EPA's original PSD regulations applied only to SO_2 and particulates. While the new law follows this policy on an interim basis, it directs EPA to promulgate PSD regulations for the other criteria pollutants (hydrocarbons, carbon monoxide, photochemical oxidants, and nitrogen oxides) by no later than August 7, 1979. These regulations will take effect one year after promulgation and must utimately be incorporated into all State implementation plans. PSD regulations for lead must be promulgated in 1980.[12]

On November 3, 1977, EPA took four regulatory actions toward implementing the Act's new PSD requirements.[13] First, the agency promulgated amendments to the pre-existing PSD regulations, conforming them to Section 168(b) of the new Act. That section expressly made certain changes "immediately effective" as of August 7, 1977 (i.e., new mandatory Class I areas, the new increments, and new Class III reclassification procedures). The second action was the proposal of regulations giving guidance to the preparation of SIP revisions called for by the new PSD review requirements of the Act. The third action was the proposal of comprehensive changes to EPA's pre-existing PSD regulations, conforming them to the new preconstruction review requirements of Section 165. The fourth action was a decision to implement the new preconstruction review and BACT requirements of Section 165 as of March 1, 1978.

EPA formally promulgated its new PSD regulations and SIP revision guidelines on June 19, 1978, three and one-half months after its original self-imposed deadline of March 1, 1978.[14] Due to the widespread public awareness of the March 1st date, however, EPA made the new PSD regulations retroactive to that date. Thus, sources which failed to obtain all necessary air pollution permits prior to March 1, 1978 had to commence construction on or before March 19, 1979 in order to be exempt from the new requirements. This was the deadline for the submission of revised SIPs to EPA.

Immediately upon promulgation, the 1978 PSD regulations were challenged by a number of industry and environmental groups, as well as state regulatory agencies. These individual lawsuits were consolidated into a single action before the U.S. Court of Appeals for the District of Columbia. On June 18, 1979, the court issued its initial ruling in Alabama Power Company v. Costle.

The Alabama Power opinion was issued by the court "per curium" which means that the specific opinions of individual judges of the court were not included. While the opinion reflected the court's final rulings on the questions presented by the petitions for review, more detailed opinions of the court were promised in the late summer or early fall of 1979. EPA's response to the court's remand order was expected to follow the issuance of these detailed opinions. However, when it became apparent that the Court would not issue its supplemental ruling until late in the year, EPA decided to go ahead and propose its new regulations.

On September 5, 1979, EPA proposed comprehensive changes to its PSD regulations in conformance with the Alabama Power summary opinion.[15] At the same time, the Agency proposed an overhaul of its nonattainment new source review guidelines to make them consistent with the proposed PSD provisions.

The D.C. Circuit Court of Appeals issued its supplemental opinion in Alabama Power on December 14, 1979.[16] With two exceptions, the final opinion made no major changes to the summary opinion.[17] EPA is now finalizing its regulations for implementing the final Alabama Power ruling. These regulations are expected to be promulgated in June 1980.

Table II summarizes the development of the PSD program.

NEW SOURCE REVIEW AND FUGITIVE EMISSIONS

New source review is the regulatory program under which major new sources and major modifications to existing sources undergo a preconstruction review process, either under PSD (generally implemented by an EPA Regional Office) or under nonattainment (generally implemented by a State through its SIP).

TABLE II

CHRONOLOGICAL DEVELOPMENT OF PREVENTION OF SIGNIFICANT DETERIORATION

Sierra Club vs. Ruckelshaus
6/11/73

EPA's Original PSD Regulations
12/5/74

The 1977 Clean Air Act Amendments
8/7/77

EPA Proposes Its Revised PSD Regulations
and SIP Revision Guidelines
11/3/77

Effective Date of EPA's Revised PSD Regulations
3/1/78

EPA Promulgates List Designating PSD and Nonattainment
Areas Pursuant to Section 107 of the Act
3/3/78

EPA Formally Promulgates Its Revised PSD Regulations
and SIP Revision Guidelines
6/19/78

Major Sources with Allowable Emissions in Excess
of 50 Tons Per Year May Have to Begin Submitting
One Year's Continuous Monitoring Data
7/7/78

Revised SIPs Due to EPA
(Note: All Sources Commencing Construction After This
Date Are Subject to the New PSD Requirements, Regardless
of When They Received Their Permit)
3/19/79

Initial Ruling in _Alabama Power Co. vs. Costle_
6/18/79

Deadline For EPA Approval or Disapproval of the Revised SIPs
7/19/79

EPA Proposes Revisions to PSD and Nonattainment Rules
9/5/79

EPA Publishes Final Revisions to PSD
and Nonattainment Rules
6/80

There are two aspects to new source review:

1) an applicability determination to decide what source or modification is subject to review, what pollutants must be reviewed, and whether PSD or nonattainment (or in some cases, both) rules apply; and

2) a substantive review, after the applicable rules are identified, to determine what technology-based standards apply (BACT, LAER), what air quality analyses must be performed, and so on.

Alabama Power focused on the applicability issues and so will this paper. The substantive issues can be briefly summarized as follows:

For PSD:

1) The application of Best Available Control Technology (BACT);

2) Ambient air quality analyses (modeling, monitoring, and other impact analyses); and

3) Consumption of the PSD increments.

For Nonattainment:

1) The application of Lowest Achievable Emission Rate (LAER);

2) Certification of statewide compliance for all major sources by the owner;

3) Obtaining of offsets (emissions reductions) from existing sources in the area of the proposed source; and

4) A net air quality benefit and reasonable progress toward attainment of the NAAQS.

It is important to note that PSD rules apply in any area where at least one NAAQS is attained.[18] Because almost every area in the U.S. is attainment for at least one criteria pollutant, the PSD review will be required for major new and modified sources, regardless of where they locate, if the source is "major" for the attainment pollutant. Accordingly, most discussions of new source review, including this paper, focus on PSD.

The remainder of this paper will focus on four specific issues and how each was addressed in a) EPA's 1978 PSD regulations, b) Alabama Power, and c) EPA's proposed PSD and nonattainment rules of September 5, 1979:

1) What sources or modifications are subject to new source review?

2) What pollutants are to be included in the review?

3) How does the source's location in a "PSD area" (an attainment or unclassified area) or nonattainment area affect the review? and

4) What is the status of the fugitive dust exemption?

Before beginning the discussion of these issues, it is useful to clarify what is meant by "fugitive emissions" and "fugitive dust".

The Clean Air Act does not provide defintions of these terms. Fugitive emissions are generally understood to refer to emissions from a stationary source that emanate from other than a stack or chimney. As discussed later EPA has proposed to define the term "fugitive emissions" as those emissions which do not pass through an opening which the owner or operator uses for ventilation, such as a stack, chimney, roof vent or roof monitor.[19] Fugitive emissions may be particulate matter, volatile organic compounds (VOC's) or any other pollutant.

On the other hand, fugitive dust is uncontaminated soil particles which become airborne as a result of human activities.[20] The most common sources are haul roads, exposed soil surfaces, and soil storage piles. Fugitive dust is particulate matter only.

Source Applicability

Section 165 of the Act imposes the new PSD preconstruction review requirements on "major emitting facilities" seeking to locate in any PSD area. The term major emitting facility is then defined as any source in one of 28 categories having a potential to emit 100 tons per year or more of any pollutant regulated under the Act. The term also embraces any source in a category other than one of the 28 listed categories with a potential emissions' increase of 250 tons per year or more of any regulated pollutant.

The term "potential emissions" (or "potential to emit") is not defined in the Act and was one of the issues under Alabama Power.

Under EPA's pre-Alabama Power regulations (hereafter, the "old" regulations), EPA defined "potential to emit" for purposes of both PSD and nonattainment new source review, as a source's maximum uncontrolled emissions. Sources with "potential" emissions in excess of the PSD thresholds (100 or 250 tons, depending on the source category) were deemed to be "major stationary sources," and, therefore, were subject to PSD. Sources could escape most of the PSD requirements on a pollutant-by-pollutant basis, however, if that pollutant's "allowable" emissions could be cut to below 50 tons per year. The basic goal of this approach was to encourage sources to reduce emissions below the 50 tpy level in order to qualify for an expedited and less expensive review.

EPA included fugitive emissions in calculating a plant's potential emissions as a matter of policy. Surface mines were considered as major sources even if their potential emissions were solely fugitive.

The court in Alabama Power reversed EPA and held that a source's potential to emit must reflect emissions after controls are incorporated. Major new stationary sources must be defined on the basis of their actual allowable emissions.

On the inclusion of fugitive emissions towards a source's potential to emit, the Court was quite specific. The court held that, although EPA does have the authority to regulate fugitive emissions and fugitive dust, generally, and mining operations specifically, EPA must address the inclusion of fugitive emissions through rulemaking, as required under Section 302(j) of the Act. The court, therefore, remanded the PSD regulations as they applied to fugitives, and directed EPA to accomplish its original objectives through formal rulemaking.

To the surface mining industry's arguement that a surface mine is not a source because a mine is not within the scope of the definition of source ("a building, structure, facility, or installation"), the Court stated that EPA had the discretion to define the term "facility" by the concept of "common sense industrial groupings" so as to encompass a source of fugitive emissions such as a major mining operation. Again, however, EPA would have to do so through rulemaking.

In response to the court's decision EPA proposed to amend the definition of "potential to emit" in the existing regulations. As proposed, the new definition would provide that the term means "the capability at maximum capacity to emit a pollutant after the application of air pollution control equipment." However, the agency has incorporated an irrebuttable presumption into the definition that a source will operate at maximum capacity around the clock, 365 days per year.

In response to the court's holdings, EPA also proposed that certain industrial fugitive emissions, to the extent reasonably quantifiable, may be included in determining whether a source or modification is "major". This proposal affects the definition of the term "potential to emit" and this applies to both PSD and nonattainment new source review.

First, EPA proposed to define "fugitive emissions" as those emissions which do not pass through an opening which the owner or operator uses for ventilation, such as a stack, chimney, roof vent or roof monitor.[21] (EPA would also delete the existing definition of fugitive dust at 40 CFR 51.24(b)(6) and 52.21(b)(6) (1978).)

Second, EPA proposed to incorporate into the existing regulations the principle that rulemaking must precede the inclusion of "fugitive emissions" in an applicability determination.[22]

Finally, the Agency proposed to list the stationary sources in Table III whose fugitive emissions are to be taken into account. Fugitive emissions will also be counted if they are from any other stationary source category which, at the time of the applicability determination, is being regulated under section 111 or 112 the Act.

EPA will be considering during 1980 the need for additional source types to be added to the list, including surface mines.

TABLE III

1) Coal Cleaning Plants
2) Kraft Pulp Mills
3) Portland Cement Plants
4) Primary Zinc Smelters
5) Iron and Steel Mill Plants
6) Primary Aluminum Ore Reduction Plants
7) Primary Copper Smelters
8) Municipal Incinerators
9) Hydrofluoric, Sulfuric, or Nitric Acid Plants
10) Petroleum Refineries
11) Lime Plants
12) Phosphate Rock Processing Plants
13) Coke Oven Batteries
14) Sulfur Recovery Plants
15) Carbon Black Plants
16) Primary Lead Smelters
17) Fuel Conversion Plants
18) Sintering Plants
19) Secondary Metal Production Plants
20) Chemical Process Plants
21) Fossil Fuel-Fired Boilers
22) Petroleum Storage and Transfer Units
23) Taconite Ore Processing Plants
24) Glass Fiber Processing Plants
25) Charcoal Production Plants
26) Fossil Fuel-Fired Steam Electric Plants

Before leaving the discussion of source applicability and fugitive emissions it is important to note three activities dealing with coal conversion that are exempted from new source review. These types of coal conversion are not subject to new source review because, either by statute or by regulation, they are not considered "modifications": Conversion to coal (or other alternative fuel):

1) Pursuant to an order under the Energy Supply and Environmental Coordination Act of 1974 (ESECA) or any superceding legislation (such as the Power Plant and Industrial Fuel Use Act of 1978);[23]

2) If, prior to January 6, 1975, the source was capable of accommodating such fuel[24]; _or_

3) Pursuant to an order or rule under section 125 of the Act ("Measures to Prevent Economic Disruption or Unemployment").

These provisions were not under review in _Alabama Power_ and remain unchanged.

Pollutant Applicability

Once one knows whether a major source or major modification is being proposed, one must determine which pollutants must be reviewed.

Under the "old" regulations, a source was subject to new source review only for those pollutants for which it was "major" (i.e., emitted in amounts greater than or equal to 100/250 tons per year). If a modification was less than 100/250 tons per year for any pollutant, the modification was not major and there was no new source review.

Alabama Power sent EPA back to the drawing board on its definition of modification, holding that EPA's interpretation was inconsistent with the language of the Act. Specifically, the court ruled that _any_ (non-exempt) modification of a stationary source is subject to the Act's PSD provisions if there is _any_ _significant_ _net_ _increase_ in emissions. Thus, the 100/250 ton threshold was rejected.

The court did hold that an insignificant, or "de minimus", net increase in emissions may be exempted by EPA. EPA has proposed a list of de minimus levels for each pollutant regulated under the Act. (See Table IV.)

This change will have far greater effect for PSD review than for nonattainment review because after _Alabama Power_ many more pollutants have been swept into new source review. Where previously review was required for only "major pollutants", now review is triggered for all pollutants emitted in greater than de minimus amounts once one pollutant becomes major.

A BACT review must be performed for each pollutant emitted in greater than de minimus amounts. However, some pollutants may be exempted from the

TABLE IV

EPA'S PROPOSED DE MINIMIS LEVELS FOR DETERMINING "SIGNIFICANT NET INCREASE"*

Carbon monoxide--100 tons per year.

Nitrogen dioxide--10 tons per year.

Total Suspended particulates--10 tons per year.

Sulfur dioxide--10 tons per year.

Ozone--10 tons per year of volatile organic compounds.

Lead--1 ton per year.

Mercury--0.2 tons per year.

Beryllium--0.004 tons per year.

Asbestos--1 ton per year.

Fluorides--0.02 ton per year.

Sulfuric acid mist--1 ton per year.

Vinyl chloride--1 ton per year

Total Reduced Sulfur:

  Hydrogen sulfide--1 ton per year.
  Methyl mercaptan--1 ton per year.
  Dimethyl sulfide--1 ton per year.
  Dimethyl disulfide--1 ton per year.

Reduced Sulfur Compounds:

  Hydrogen sulfide (see above).
  Carbon disulfide--10 tons per year.
  Carbonyl sulfide--10 tons per year.

* Note - EPA has added a second set of ambient impact "de minimis" levels to limit the air quality review requirements only for certain pollutants which the source would have the potential to emit, in significant amounts but which have an insignificant ambient impact.

air quality analysis part of new source review if, as a result of screening modeling, the pollutant is below a second de minimis level which is based on air quality impacts.

For nonattainment review, pollutant applicabililty is far narrower. To trigger new source review, a source or modification must be major for a pollutant for which the area is nonattainment. And once nonattainment review is triggered, other pollutants are not swept in as under PSD rules.

An example will illustrate this change. Under the "Old" rules, the addition of a coal pile with fugitive emissions of 15 tons per year would not result in new source review because the modification was not major (100/250 tons per year). After Alabama Power and under EPA's proposed de minimus levels, the addition of the coal pile is a major modification (being greater than the 10 tpy de minimus level for particulates), and a BACT review for the coal pile would be required. However, detailed air quality analyses may be avoided if the facility can demonstrate that the impact is less than 5 μg/m^3 (24 hour average).

Geographic Applicability

The next stop in the new source review applicability determination is deciding which set of regulations apply for the pollutants subject to the review - PSD, nonattainment of both.

Under the 1977 Clean Air Act Amendments, all areas of the nation have been designated as subject either to PSD or nonattainment requirements. With respect to new source review, however, the "old" EPA regulations focused on the area impacted by the source, irrespective of the attainment status of the area in which the source sought to physically locate. Specifically, EPA's PSD regulations extended the permit requirements of section 165 to all sources, wherever located, if the emissions from the source had a signification impact on any clean air area.

The court held in Alabama Power that the Act's PSD requirements are not triggered by sources located in nonattainment areas simply because they have an adverse impact on a clean air area within the same State. Only where the source is located in a nonattainment area of a neighboring state will its impact on adjacent clean areas trigger the PSD review. The court's reasoning is based upon a number of provisions in the Act which seek to prevent interstate PSD conflicts. With respect to intrastate air quality management planning, however, the court noted a "federalist policy" of deferring to the States on matters relating to their internal growth management. The final court ruling indicates that PSD permits cannot be required for sources in nonattainment areas even if interstate impacts are involved. SIP's, however, must address such impacts.

Although EPA has petitioned the DC Circuit for reconsideration on this aspect of the decision, it appears doubtful that the agency will succeed in changing the court's mind. In its September 5, 1979 proposed regulations, EPA has, therefore, developed a change in prior policy designed to overcome a potential gap in the New Source Review program which could materialize.

Specifically, under the "old" regulations, proposed major sources in designated nonattainment areas with no significant impact on the violations can be exempted from nonattainment requirements because they are made subject to PSD preconstruction review. But, under Alabama Power and the regulations now being proposed, such major sources would be able to avoid both PSD and nonattainment NSR requirements.

EPA has determined that such a result is contrary to the intent of the Clean Air Act and has, therefore, proposed to extend the nonattainment NSR requirements of both the Offset Policy and Section 173 of the Act to cover major sources everywhere in the designated nonattainment area.[25] This rule would apply regardless of whether the source could demonstrate that it would not significantly impact the specific point(s) of violation.

The Fugitive Dust Exemption

Following the 1977 Amendments to the Clean Air Act, EPA created through rulemaking a partial exemption from new source review requirements for major emitting facilities of fugitive dust. The regulation maintains the requirement that such sources apply best available control technology (BACT), but exempts them from the otherwise-required showing that particulate emissions from the facility will not exceed either the applicable national ambient air quality standards (NAAQS) or the allowable increments.[26]

In Alabama Power, the court vacated (i.e., eliminated) the exemption and sent it back to EPA for further consideration. As in the case of fugitive emissions, the court held that EPA had the legal authority to accomplish its stated objective, but had failed to comply with the rulemaking requirement imposed by the Act.

In remanding the fugitive dust exemption for agency reconsideration, the court suggested a regulatory approach under which fugitive dust could become a "regulated" pollutant (by controlling it under Section 111 of the Act) but would not be a "criteria" pollutant within the meaning of the national ambient standards or the PSD increments. Under this approach, major new and modified sources of fugitive dust would have to control emissions with BACT, but would not have to model its air quality impact with respect to the ambient particulate increments or standards, thereby achieving the same result as under the exemption.

However, EPA has proposed to eliminate the exemption entirely, both from the PSD regulations and from a parallel provision in the offset ruling.[27] The agency gave no reason for its decision to eliminate the exemption. It is important for surface mining operators to note, however, that under the Surface Mine Control and Reclamation Act (SMCRA), the Office of Surface Mining (OSM) within the Department of the Interior has begun to regulate the fugitive dust aspects of mining in a manner substantially more stringent than EPA. OSM regulations will require, among other things, the preparation of a fugutive dust plan and the imposition of fugitive dust control technology.[28]

CONCLUSION

The Alabama Power decision will have a significant impact on the regulation of fugitive emissions for the forseeable future. But interestingly, the impact will not be due to the sections of the decision directly addressing fugitive emissions and fugitive dust. The impact will come from the greater number of sources and modifications subject to new source review and EPA's implementation of the de minimus concept.

The court's holding that EPA may include fugitive emissions toward determining a source's "potential to emit" in order to determine whether there is a major source or modification only placed a temporary road block in EPA's path. By the time this paper is published, EPA will have amended the definition of "potential to emit" to include fugitive emissions to the extent reasonably quantifiable for most major source categories (although surface mines have not yet been included).

Of more concern is the whole change in the concept of "major modification". Because this term now means, for PSD purposes, any significant net increase of any pollutant once the source is major for any (including a different) pollutant, there will potentially be many more "major modifications" and many more new source reviews required. (For nonattainment purposes, the "significant net increase" must still be for the pollutant for which the source is major).

This increase in PSD new source reviews will be substantial unless the bubble policy can be easily used by a source to achieve, through an increasingly complex "numbers game", no net increase in a source's emission rate. As fugitive emissions become more quantificable, sources will have to obtain offsets for such activities as material storage piles and haul roads. Depending on the final de minimus level for particulate matter, the addition of coal piles alone could trigger new source review. Any facility contemplating conversion to coal should, however, carefully review the available exemptions from new source review for certain conversions.

Once new source review is begun, either partially or entirely due to sources of fugitive emissions, the substantive aspects of the review come into play. What is BACT or LAER for sources of fugitive emissions - for coal piles, for haul roads, for surface mines? What is involved in performing the air quality analysis - the modeling and the monitoring - of these emissions? These two questions, together with how to "reasonably quantify" these emissions, will be the fugitive emissions issues of the '80's.

FOOTNOTES

1. 13 ERC 1225 (C.A.D.C. 1979).

2. 41 FR 55524.

3. 39 FR 42510] 40 CFR 52.21.

3a. For a discussion of the development of the PSD program, see Raffle, Bradley I., "Prevention of Significant Deterioration and Nonattainment Under the Clean Air Act - A Comprehensive Review" Environment Reporter, Monograph No. 27 (May 4, 1979).

4. 39 FR 42510 (December 5, 1974).

5. 43 FR 8962.

6. 40 CFR 81.

7. Clean Air Act (CAA) Section 162.

8. CAA Section 162.

9. CAA Sections 165 and 169(1). The Amendments defined a major source in terms of its "potential to emit" but do not define the term "potential." EPA's 1978 PSD regulations define "Potential to emit" as the capability at maximum capacity to emit a pollutant in the absence of air pollution control equipment. This was at issue in Alabama Power.

10. CAA Sections 165(a)(4) and 169(3).

11. CAA Section 165(c).

12. CAA Section 166.

13. 42 FR 57459.

14. 43 FR 26380] 40 CFR Sections 51.24 and 52.21.

15. 44 FR 51924.

16. 13 ERC 1993 (C.A.D.C. 1979).

17. These changes relate to the need to obtain a PSD permit for interstate air quality impacts and the need to monitor for noncriteria pollutants such as H_2S. The court relaxed its original position on each of these issues.

18. CAA Section 161.

19. See Proposed Sections 51.24(b)(20) and 52.21(b)(20) (1979).

20. 40 CFR 51.24(b)(6) and 52.21(b)(6) (1978).

21. *Supra*, n. 19.

22. See 44 FR 51930 and Proposed Sections 51.24(b)(3) and 52.21(b)(3) (1979).

23. 40 CFR 52.21(b)(2)(c) (1978) and 40 CFR 51, Appendix S, Paragraph II(A) (5) (ii) (d).

24. 40 CFR 52.2(b)(2)(d) (1978) and 40 CFR 51, Appendix S, Paragraph II(A) (5)(ii)(c).

25. See Proposed Sections 51.24(i)(2)(i) and 52.21(i)(8)(i) (1979).

26. 40 CFR 51.24(k)(5) and 52.21(k)(5) (1978).

27. 44 FR 3274.

28. 30 CFR Parts 782-784. See especially Sections 783.18 and 784.26.

PARTICLE PRODUCTION FROM SURFACE MINING:

PART 1--VERTICAL MEASUREMENTS

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ABSTRACT

An investigation of the vertical extent and downwind transport of fugitive dust plumes resulting from various operations at a surface coal mine was conducted using a tethered balloon sampling system. This EPA-sponsored field study took place concurrently with a Bureau of Land Management-sponsored field program conducted by the USDA's Forest Service and Colorado State University to assess the overall air quality impact of strip mine activities on the surrounding environment.

A balloon was used to carry aloft three lightweight wind directional particle samplers. One sampler was attached directly to the balloon; the other two were attached to the tetherline at selected distances from the balloon. This arrangement allowed for the simultaneous collection of dust samples at three heights above the ground at various downwind distances from the mine operations. A fourth sampler was located near the balloon launch site to monitor ground level concentrations. Dust samples were collected on Nuclepore and Millipore filter substrates which were analyzed by optical and scanning electron microscopy.

The size distribution, concentration and composition versus height of the collected dust samples are presented. Time lapse movies of mining activities at the test site during tethered balloon sampling are also discussed.

INTRODUCTION

For the past 3 years, the Denver Research Institute (DRI) has been involved in developing and utilizing balloon-borne particle sampling systems which possess both vertical and horizontal mobility and are capable of sampling at specified altitudes for extended periods of time. Two of the systems developed employ remote controlled samplers and have been used to monitor emissions from the plumes of coal-fired power plants[1] and a portland cement plant.[2] The third sampling system, which is described in this paper, was developed to investigate the vertical extent and downwind transport of fugitive particle emissions from point and nonpoint sources. The system was recently employed to monitor dust emissions from various operations at a surface coal mine and to evaluate the feasibility of using the tethered balloon sampling method to ultimately determine emission factors using an exposure profiling technique.

The DRI field study at the surface coal mine in Colorado was sponsored by the Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. The study took place concurrently with a Bureau of Land Management-sponsored field program performed by the U.S. Forest Service and Colorado State University to assess the overall air quality impact of strip mine activities on the environment.

A preliminary field test at the mine was conducted from June 4 to June 8, 1979, to check out and evaluate sampling techniques. A more extensive field investigation was conducted at the mine from July 30 through August 8, 1979. Results of the DRI study for the latter test period are presented, including the evaluation of selected airborne dust samples from a dragline operation versus dust from hauling, dragline, dressing and scraping operations, as well as dust samples from an active haul road. The mineral content of selected soil and road bed samples is also presented. Documentation of balloon sampling and mine site activities using time lapse photography is discussed.

BACKGROUND

It is now widely recognized that fugitive particle emissions contribute significantly to the measured levels of total suspended particulates (TSP) found in both urban and rural environments. These emissions are believed to be responsible for the failure of many areas to attain the national primary air quality standards for TSP. Major open sources of fugitive emissions include unpaved roads, paved roads, surface mines, storage piles, construction activities, agricultural tilling, wind erosion of harvested cropland and forest and brush fires, including both wildfires and prescribed burns.[3] Other sources include iron and steel foundries, smelters, and refineries.[4,5,6] Considerable effort is being devoted by numerous researchers in establishing the particle emission levels and rates from fugitive sources so that cost effective control strategies can be developed for such emissions.

Of the fugitive sources listed above, open sources (except forest and brush fires) emit particles primarily in a coarse size range of greater than approximately 2.5 µm in equivalent aerodynamic diameter. These particles, classified as mechanically generated, are believed to be the most significant sources of fugitive emissions contributing to measured ambient TSP levels. Fugitive particle emissions produced by combustion processes, such as from forest and brush fires and from furnace operations at foundries and smelters, are typically in a fine particle size range less than 2.5 µm. The chemistry of the coarse versus fine particles also differs: coarse particles are usually more basic; and fine particles, more acidic.[7]

The traditional method of monitoring airborne particles from fugitive sources has been to use ground-based high-volume samplers. The samplers are usually at considerable distances both upwind and downwind from the source being sampled. Dispersion modeling is normally used to interpolate the source strength from the HiVol data. Considerable error can be incurred when using this technique because of the often limited number and location of sampling sites and due to the current simplicity of the atmospheric dispersion models. Complications are further increased when the source is not well defined.

Samplers mounted on towers have been used successfully to characterize fugitive dust emissions from paved and unpaved roads employing an "exposure profiling" technique which is based on the isokinetic profiling concept used for conventional source testing.[8] Particulate emissions are measured directly downwind of the source being sampled by placing a grid of samplers in the effective cross-section of the plume. Emission factors are subsequently determined by a mass-balance calculation. The exposure profiling technique eliminates the need to use dispersion models to estimate emission rates from fugitive sources. A two dimensional vertical array of samplers must be used when sampling a point or area source with this technique while line sources (e.g., haul roads) require a one dimensional vertical grid of samplers.

Major limitations of the exposure profiling technique are the practical height of the sampling towers and their lack of mobility. Results of the study presented here indicate that these limitations can be overcome using balloon systems so that the exposure profiling technique can be extended to a larger number of fugitive source sampling applications.

TETHERED BALLOON SAMPLING SYSTEM

The sampling system basically consists of a balloon system, wind vane samplers and a ground-based sampler.

Balloon System

A commercially available blimp-shaped balloon having a buoyant gas capacity of 3.25 m^3 is used as the airborne platform for the three wind vane samplers discussed below. Tethered balloons up to this size do not require Federal Aviation Administration waivers to Federal Aviation Regulations, Part 101, in order to be operated. When inflated with helium, this balloon has a static lift of 1.9 kg at sea level. The balloon is constructed of polyethylene and, for ease in observation and safety, is red. The balloon is attached via a tetherline to a portable winch which contains a battery operated forward/reverse, variable speed motor for tetherline control. a 12-volt sealed lead/acid battery pack and charger system have been incorporated into the winch housing so that the winch is totally self-contained. The winch weighs 27 kg including the battery pack modification. The extremely lightweight tetherline has a breaking strength of 535 newtons and a mass to length ratio of 0.4 kg/km.

This balloon system is capable of lifting a package weighing 1.2 kg to maximum altitudes of 800 to 1,000 m in winds of 6 to 8 m/s. Flight performance of the balloon is still reasonable in winds of 10 to 12 m/s but the maximum altitude attainable is somewhat reduced. The balloon is designed to survive in winds up to 20 m/s.

Wind Vane Samplers

Three wind directional particle samplers, each weighing 400 g, were employed in this study. A schematic of this sampler type is shown in Figure 1. The vertical tube of the sampler attaches to the horizontal tube at a point where the wind vane balances the forward tube extension such that the extension is always horizontal. The tubes and wind vane are fiberglass. A 37 mm filter cassette is attached to the front end of the horizontal tube. An assembly housing the pump, battery pack and voltage regulator is attached to the bottom of the vertical tube. The weight of these components ensures that the sampler maintains the orientation shown in Figure 1. The samplers are attached to the balloon or tetherline by nylon lines. Swivels are tied to the ends of the nylon lines that attach to the samplers while quick disconnect clamps are tied to the ends that attach to the balloon or tetherline. The wind vane configuration ensures that the samplers point into the wind during sampling. Observations have shown this to be the case even in very light winds (<1 m/s).

Two of the wind vane samplers are equipped with a diaphragm pump; the third uses a piston pump. All pumps are powered with battery packs consisting of three lithium cells wired in series which provide 8.1 volts. This voltage is regulated down to 5 volts to ensure constant pumping rates. Flexible tubing is used to connect the pumps to the 37 mm filters held in plastic cassettes. The sampling probe shown attached to the filter cassette in Figure 1 was not used during this field study: all airborne dust samples were collected on open-faced filters. Each sampling pump is activated at the time that the associated sampler is launched. For this study, 0.2 μm Nuclepore filter substrates were employed; the corresponding air sampling rates of the diaphragm pumps and the piston pump were 2.75 ℓ/m and 1.2 ℓ/m, respectively. Millipore filters having an effective pore size of 0.8 μm were also used, resulting in air flow rates of 5.1 ℓ/m and 3.4 ℓ/m for the diaphragm and piston pump samplers, respectively.

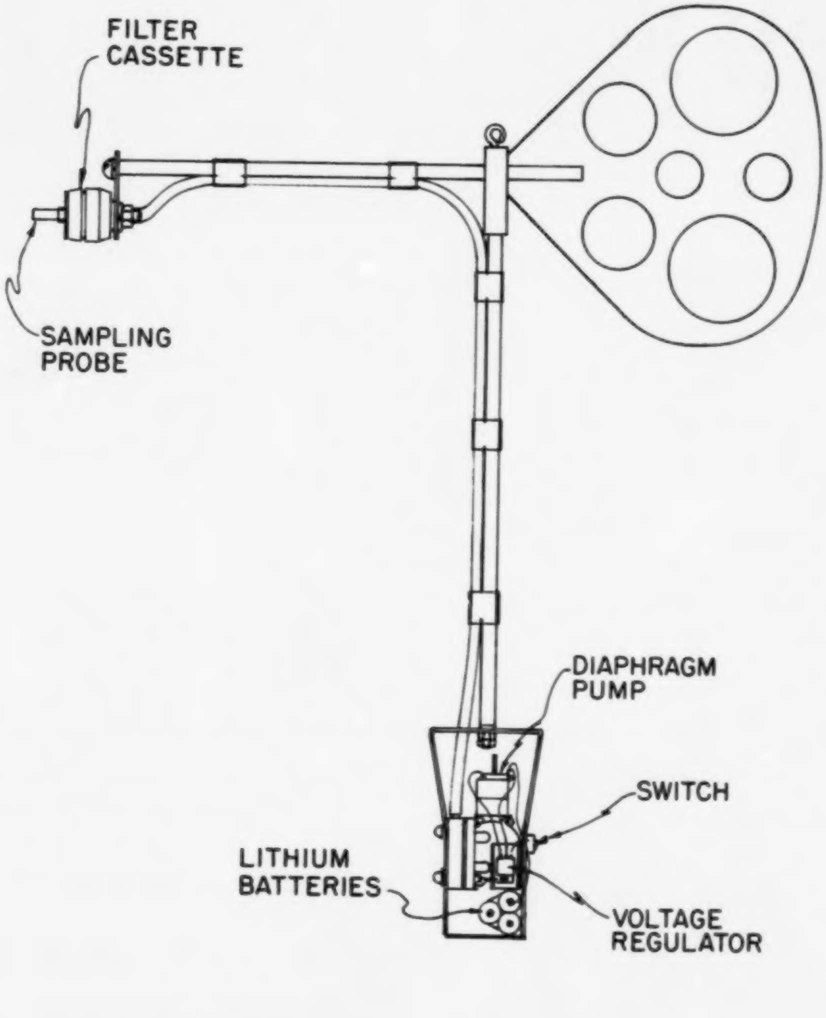
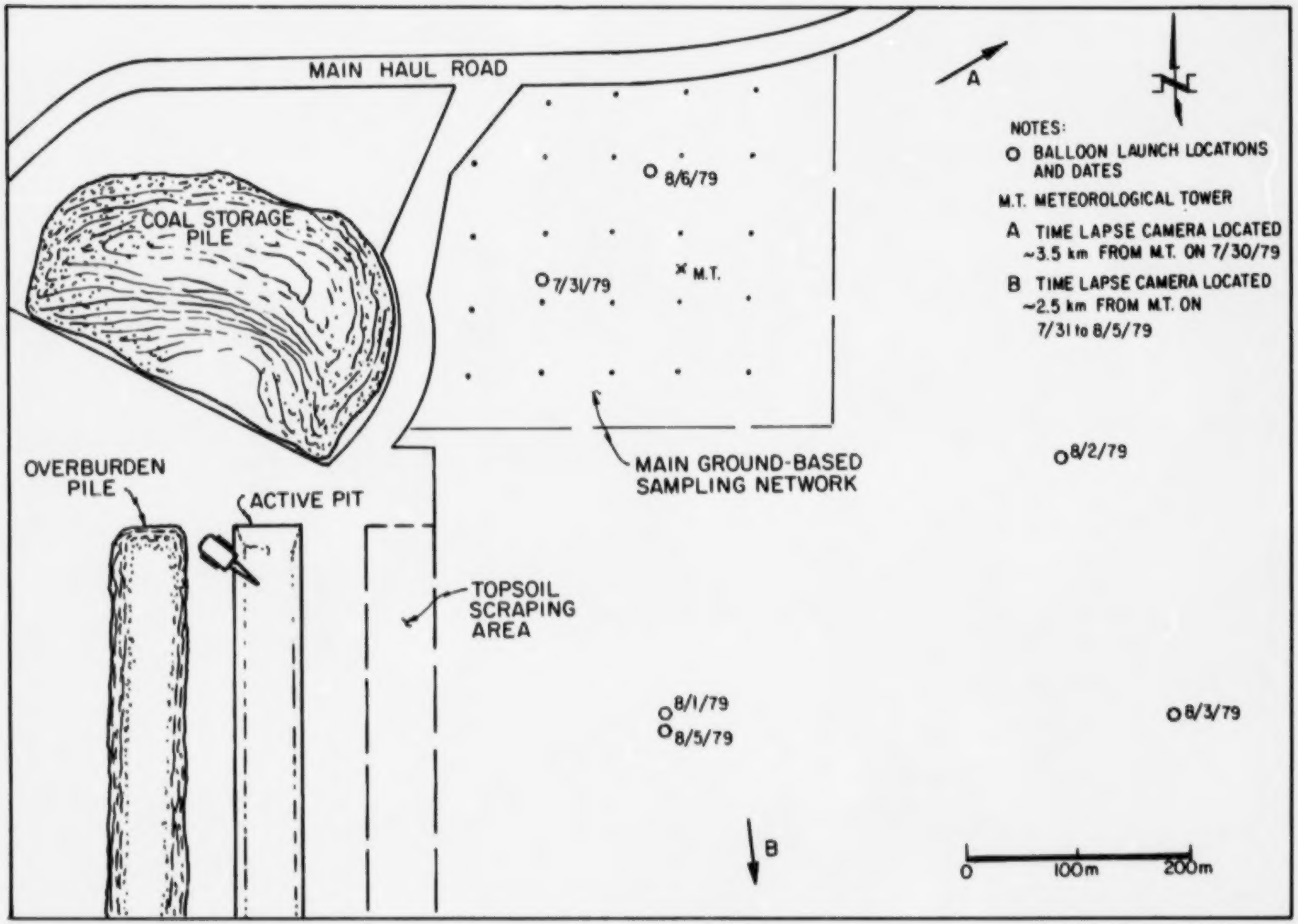

FILTER
CASSETTE
SAMPLING
PROBE
DIAPHRAGM
PUMP
SWITCH
LITHIUM
BATTERIES
VOLTAGE
REGULATOR

Figure 1. Wind vane particle sampler.



MAIN HAUL ROAD
COAL STORAGE PILE
OVERBURDEN PILE
ACTIVE PIT
TOPSOIL SCRAPING AREA
MAIN GROUND-BASED SAMPLING NETWORK
8/6/79
7/31/79
M.T.
8/2/79
8/1/79
8/5/79
8/3/79
A
B
N
NOTES:
O BALLOON LAUNCH LOCATIONS AND DATES
M.T. METEOROLOGICAL TOWER
A TIME LAPSE CAMERA LOCATED ~3.5 km FROM M.T. ON 7/30/79
B TIME LAPSE CAMERA LOCATED ~2.5 km FROM M.T. ON 7/31 to 8/5/79
0
100m
200m

Figure 2. Strip mine sampling site.

Ground-Based Sampler

In addition to the three balloon-borne samplers, a fourth sampler equipped with a piston pump was always located near the balloon launch site to monitor dust concentration at ground level. This sampler was not wind directional. It was positioned at a height just above the local vegetation with the open-faced filter cassette pointing upward.

FIELD OPERATIONS

A description of the field site, the operation of the balloon sampling system, the collection of soil samples, and the documentation of sampling/mining operations are discussed.

Field Site

The mine site, in arid western Colorado, is on the north face and near the bottom of a gently sloping mountain range. Its elevation is 1,950 m. In terms of dispersion modeling, the terrain would be classified as relatively complex. Dry conditions existed during field sampling. Morning temperatures varied between 8°C and 15°C; afternoon temperatures varied between 31°C and 40°C. Surface radiational inversions existed most mornings. Winds were predominantly from the west. During the mornings, the winds were light and sometimes variable; by early afternoon, they would become strong and often gusty. The site in Figure 2 shows balloon launch locations and dates of balloon sampling. Main elements of the site consisted of an active coal pit, a coal storage pile, haul roads and a topsoil scraping area. A dragline removed overburden from the pit, coal was loaded in the pit and, on most days, the pit coal seam was blasted. During several of the sampling days, topsoil was removed from an area east of the pit and coal from the storage pile was loaded onto haul trucks. The storage pile and the area adjacent to the pit were dressed periodically.

Balloon Sampling Operations

Balloon sampling consisted of first locating the balloon system at a selected distance downwind from the mine operation(s) to be sampled. The first sampler would then be attached to the balloon and the pump of this sampler would be activated by connecting the battery leads shown in Figure 1. The balloon would be launched until a selected length of tetherline was reeled off the winch. The winch spool would be stopped, the second sampler would be attached to the tetherline and its pump would be activated. Again the winch spool would be actuated until the appropriate length of tetherline was reeled out. The winch would be stopped, the third sampler would be attached to the line and its pump would be activated. Finally, the winch would be started and additional tetherline would be run out until the balloon reached the desired uppermost sampling height. Appropriate distances were previously marked on the tetherline to assist in placing the samplers at the desired vertical separation distances. The ground-based sampler would also be activated at this time.

Flight operations were conducted at downwind distances varying from 150 to 1,000 m from selected mine operations with sampling heights up to 120 m. Sampling times were typically 4 to 6 hours.

Three balloon sampling operations, in which the collected dust samples have been examined in detail, are discussed below. A log of these operations is presented in Appendix A.

Dragline Versus Additional Mining Operations

From 0700 hours to 1143 hours MDT on August 1 and again from 0830 hours to 1516 hours on August 5, balloon sampling was conducted at the same launch site shown in Figure 2. During both sampling periods, the wind at an altitude of 75 m was predominantly from the west. The surface wind velocity measured by a ground based meteorological station varied from 1.8 m/s to 3.1 m/s and from 1.3 m/s to 2.7 m/s during the sampling periods on August 1 and August 5, respectively. The launch site was approximately 400 m east of the dragline operation at the active coal pit. Mine activities during the sampling period on August 1 included coal hauling, overburden removal by the dragline, dressing operations and topsoil scraping, while only the dragline was in operation on August 5. Dust samples were collected at elevations of 0.5 m, 10 m, 20 m and 75 m.

Hauling Operations

A balloon sampling operation was conducted from 1155 hours to 1440 hours on August 6 to investigate the extent of dust emissions from an active haul road. During this sampling period, the surface wind velocity was 2.2 m/s to 3.1 m/s. The balloon was located approximately 150 m directly downwind from a curve in the haul road and dust samples were collected at an elevation of 30 m.

Soil Sample Collection

Loose soil samples were collected from the middle of the main east-west haul road, from the spoils of an overburden drill hole and from the overburden pile adjacent to the dragline. These samples were used to identify the typical mineral composition of the mine site. The samples were collected by hand and were stored in sealed plastic bags for later laboratory analysis.

Documentation of Sampling/Mining Operations

A 16 mm zoom lens Bolex movie camera equipped with an MRI intervalometer was used to take time lapse movies of all tethered balloon sampling operations. The movies were taken to document the downwind sampling distances, the activities at the mine site and the general atmospheric conditions during sampling. The camera locations are shown in Figure 2. The camera framing rate was typically one frame every 3 seconds.

RESULTS

Analyses of airborne particles, bulk soil samples, and time lapse movies are discussed.

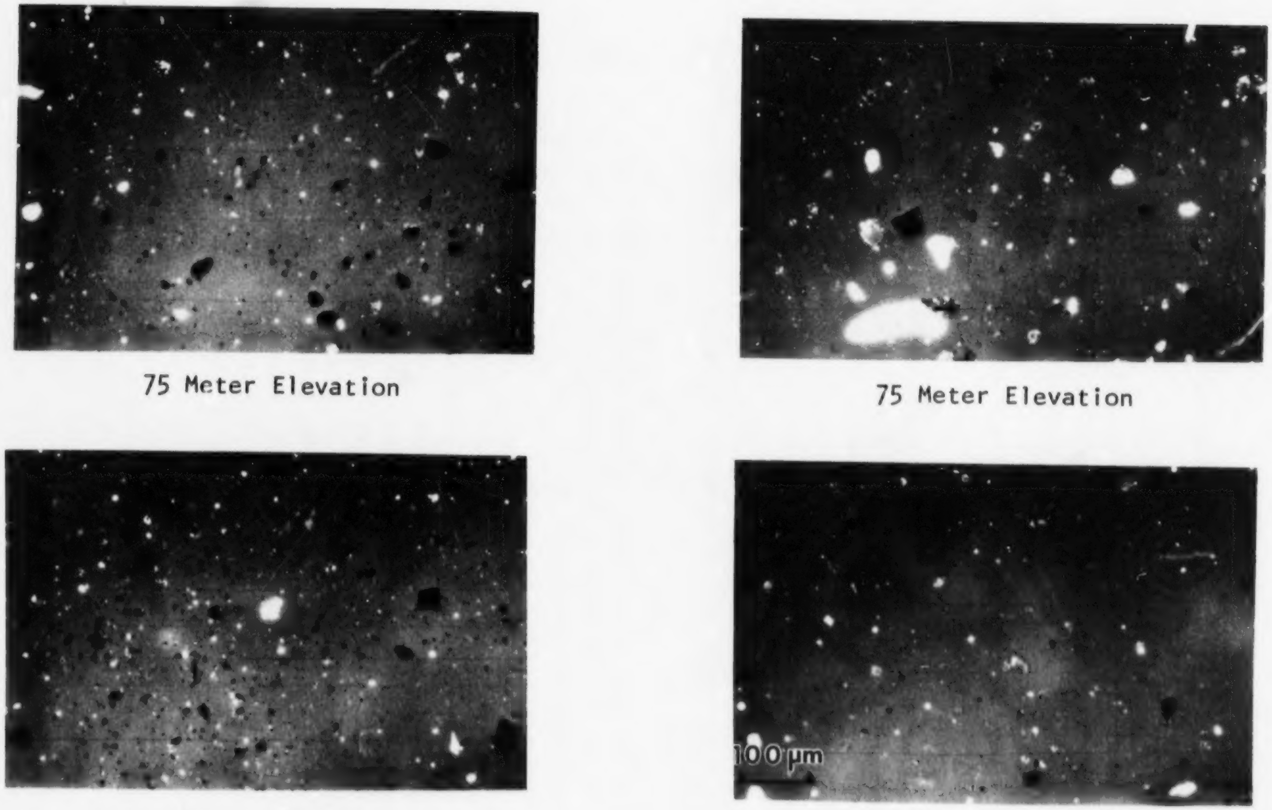
Particle Analysis

Both optical and scanning electron microscopy were utilized to determine the composition, size distribution and concentration of the collected particles. In general, optical microscopy was limited to larger particles (diameters $\geq$ 5 μm) which permitted rapid determination of coal and mineral components. Scanning electron microscopy was employed to perform detailed size and compositional analyses of particles ranging from 0.5 μm to 100 μm in diameter.

All Millipore filters exposed in the field were examined using optical microscopy. In the laboratory, mid-sections of the Millipore filters were carefully excised and permanently mounted on microscope slides. Examination during the mounting procedure assumed that particle displacement was minimal. A mixture of 4 percent flexible collodian in amyl acetate was used to clear the Millipore filter material and adhere particles to its surface. After the collodian/amyl acetate mixture dried, a cover slip was added using Permount to make a permanent slide for future observations.

Upon returning to the laboratory, it was observed that some of the particles collected on the Nuclepore filters had become dislodged from the filter substrate and had redeposited on the walls of the capped cassettes. This was especially noticeable for the fraction of the larger particles. Subsequently, the particles on these filters and filter cassettes were resuspended and transferred to glass vials using filtered (0.2 μm filter material) ethyl alcohol. Resuspension was carried out in a positive pressure glove box. Air to the glove box was filtered through dual absolute filters. Samples for subsequent optical and electron microscopy were prepared by refiltering the resuspended particles through 0.2 μm Millipore media. Filter mid-sections to be used for electron microscopy were mounted on SEM stubs using double sided adhesive tape. A gold/palladium alloy was then vacuum sputtered onto the samples to make them electrically conductive for high resolution electron beam observations. The thickness of the gold/palladium coating was approximately 10 nm.

The optical analysis was performed using a Zeiss Photomicroscope II at magnifications of 36x, 160x and 250x. Polarized light with the polarizing elements slightly out of phase was used to permit simultaneous recording of mineral and coal particle images. Highly opaque images were assumed to be coal. Inhomogeneous particles containing both coal and mineral were commonly observed. For the purpose of the optical analysis, any particle containing coal was classified as a coal particle. Particle counting was performed from photomicrographs, examples of which are shown in Figure 3.



August 1, 1979

75 Meter Elevation

0.5 Meter Elevation

August 5, 1979

75 Meter Elevation

0.5 Meter Elevation

Figure 3. Optical micrographs of sampled particles (mine operations: August 1 - hauling, dragline, dressing and scraping; August 5 - dragline only).

More detailed information was obtained using a Philips 501B scanning electron microscope equipped with an EDAX 9100/60 energy dispersive x-ray analyzer. A number of randomly selected fields of 80x and 640x were examined for each sample. The EDAX analyzer was used to identify the relative elemental composition of the particles. An example of the x-ray analysis of three types of particles collected during this field program is illustrated in Figure 4. The gold peak recorded in the sample spectrum is produced by the gold/palladium alloy coating. It is notable that the coal particle contains significant amounts of elements normally associated with minerals (Al, Si, K, Ca, Fe) whereas the carbon black particle, probably diesel, produces no observable x-ray spectra. Carbon black particle aggloremates were only rarely observed in the samples examined. In general, particles having a gold peak the same as or less in magnitude than Si (or other major elemental peaks) were classified as mineral in this analysis. As with the optical microscopy, particle counting was performed from photomicrographs. The composition of the particles was noted directly on the micrographs prior to counting. Examples of the SEM micrographs are shown in Figure 5.

Equivalent spherical diameters of the basically irregular mineral and coal particles were estimated by averaging the maximum length of each particle and its maximum width taken at right angles to the length. All particles observed on a micrograph were classified by size and composition and tallied into a size class based upon a geometric progression of the $\sqrt{2}$.[9] For example, 13 size intervals, ranging from 0.6-1.0 μm to 60.0-85.0 μm, were employed for mineral and coal particles observed on the SEM micrographs. After classifying the mineral and coal particles separately, the particles counted per interval at 640x were extrapolated to the number which would be present at a magnification of 80x. For intervals which overlapped the two magnifications, weighted averages of the number of observed particles were employed. The total number of particles in each interval across the entire active filter was then calculated and, in turn, divided by the total volume of air sampled through the filter.

The mid-size diameter of each size interval was used to calculate a spherical particle volume. These volumes were then multiplied by the appropriate number counts per volume of air sampled and by assumed particle densities so that cumulative and differential mass distributions as functions of particle size could be plotted. The assumed density of the mineral particles was 2.6 g/cm^3; that for the coal particles, 1.4 g/cm^3.

Cumulative mass distributions for particles sampled on August 1, 5 and 6 are presented in Figures 6, 7 and 8, respectively. The straight lines through the data points were fitted using a least squares routine applied in log-normal space. If a distribution is log-normal, it will occur as a straight line when plotted on a log-probability graph. In general, the data is approximately log-normal. The mass median diameters d_{gm}, are the 50 percent values of the distributions while the geometric standard deviations, σ_g, are the 84.1 percent values divided by the 50 percent values. Table 1 summarizes d_{gm}, σ_g, and the total number of mineral and coal particles counted from the micrographs for each sample analyzed.

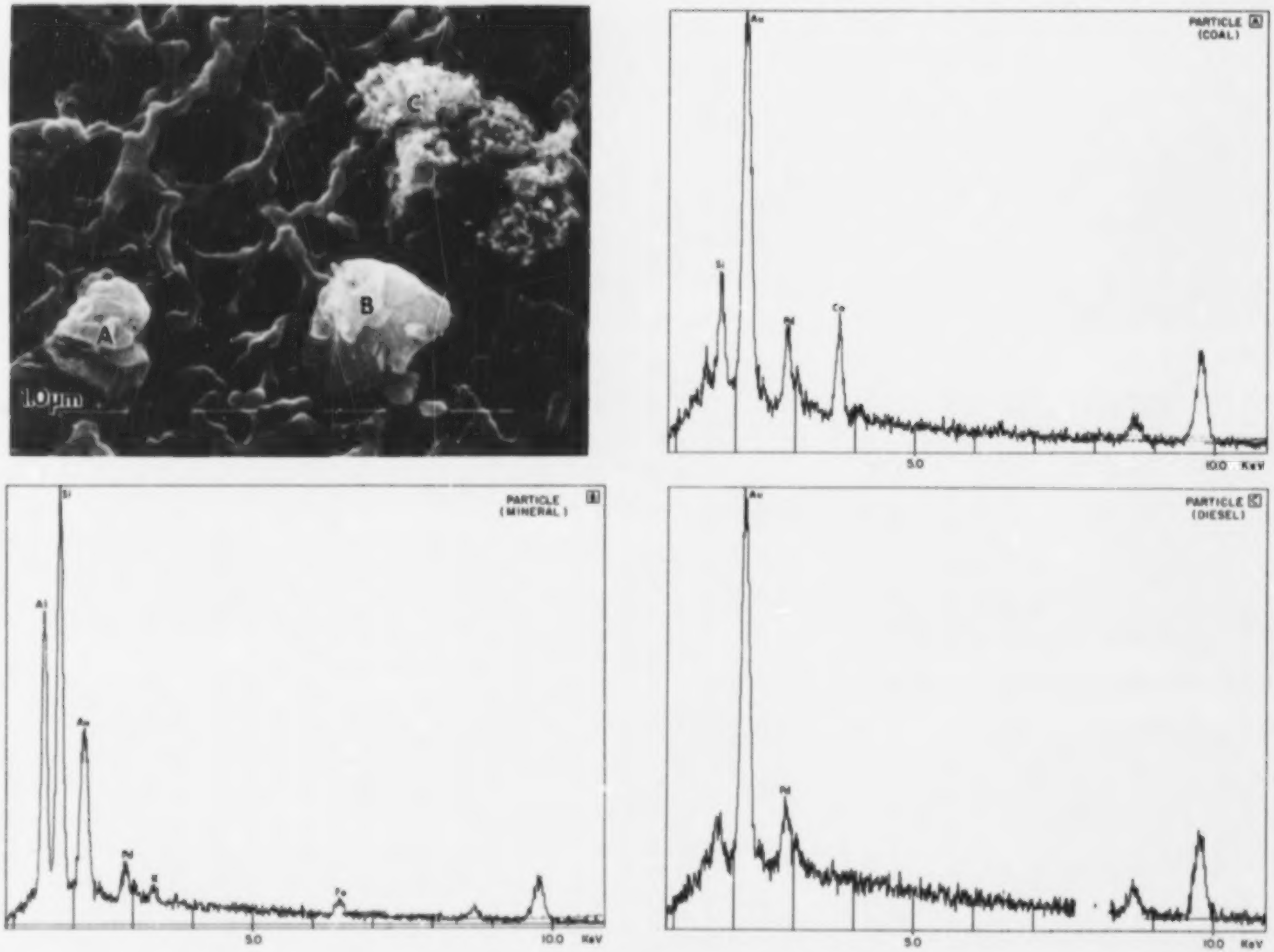
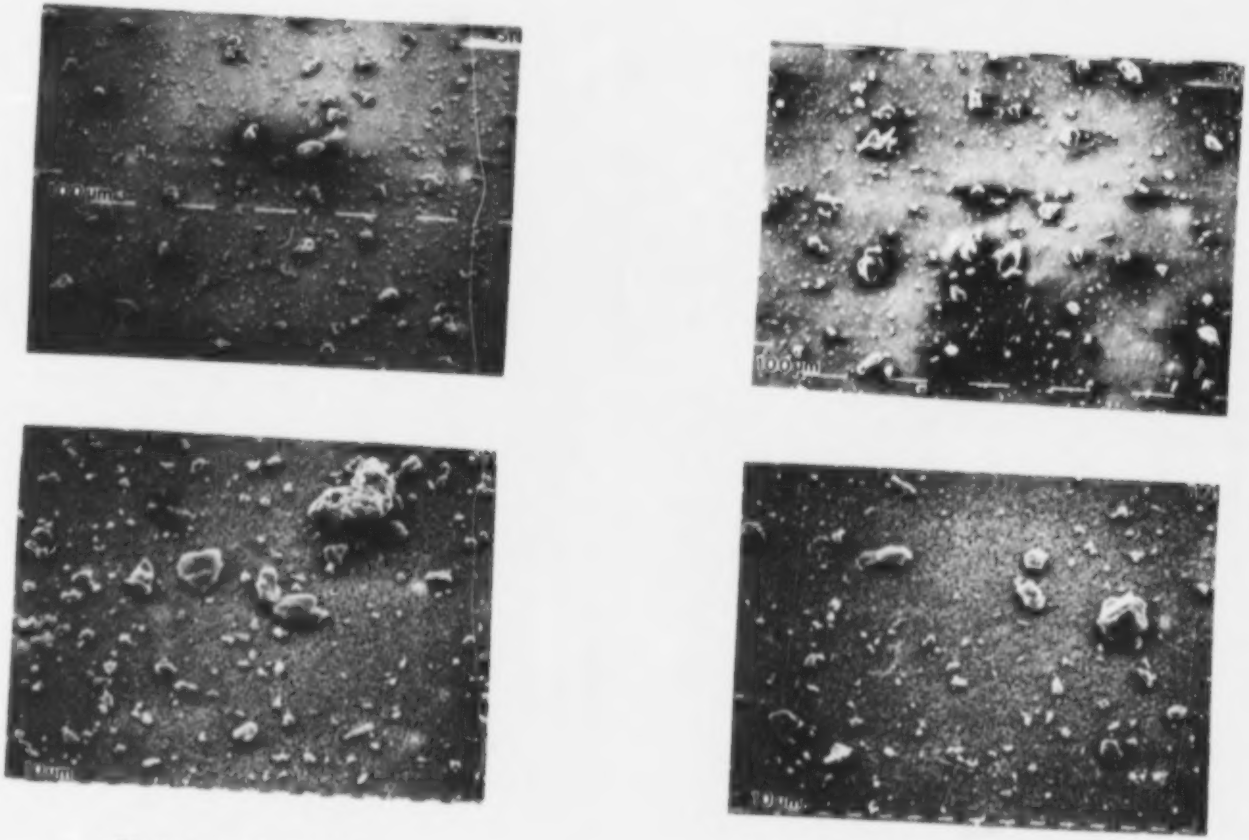


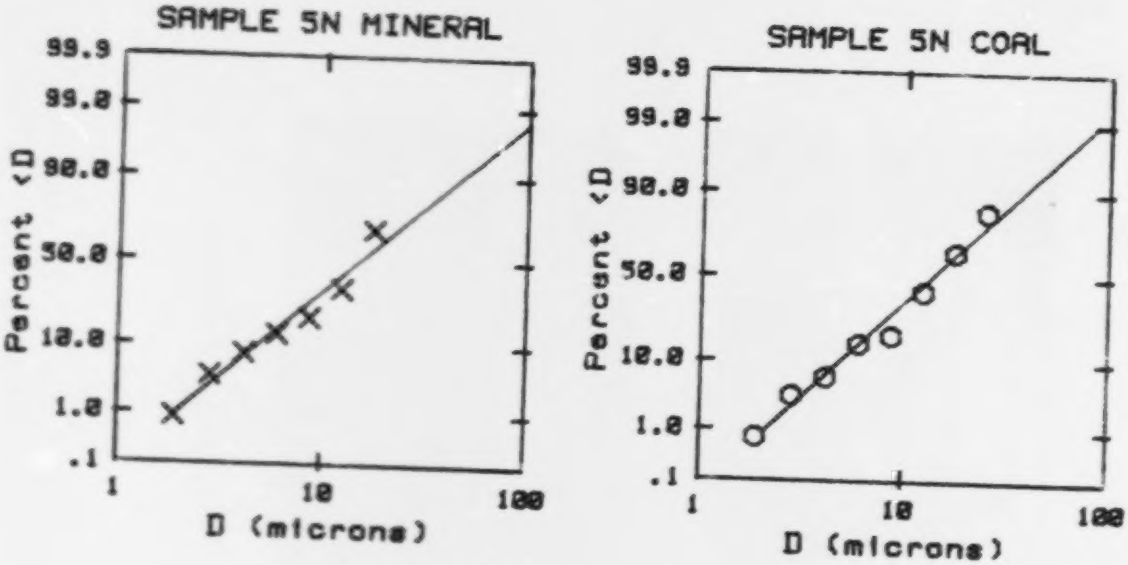
Figure 4. SEM micrograph showing particle types sampled at the strip mine and associated x-ray spectra.


100µm
10µm
100µm
10µm

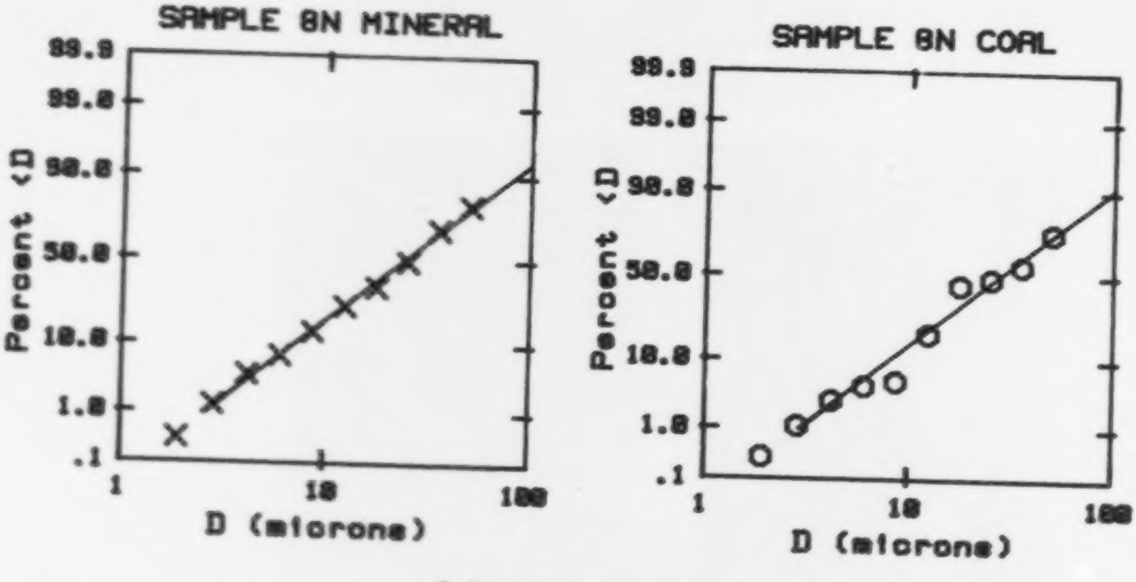
75 Meter Elevation

0.5 Meter Elevation

Figure 5. SEM micrographs of particles sampled on August 1, 1979 (mine operations: hauling, dragline, dressing and scraping).

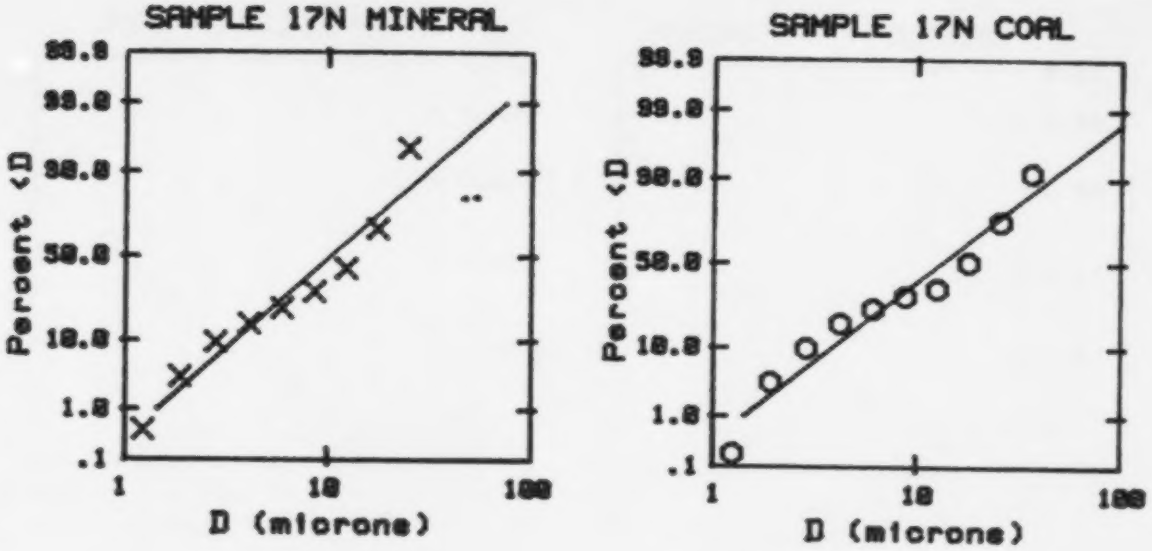


75 Meter Elevation



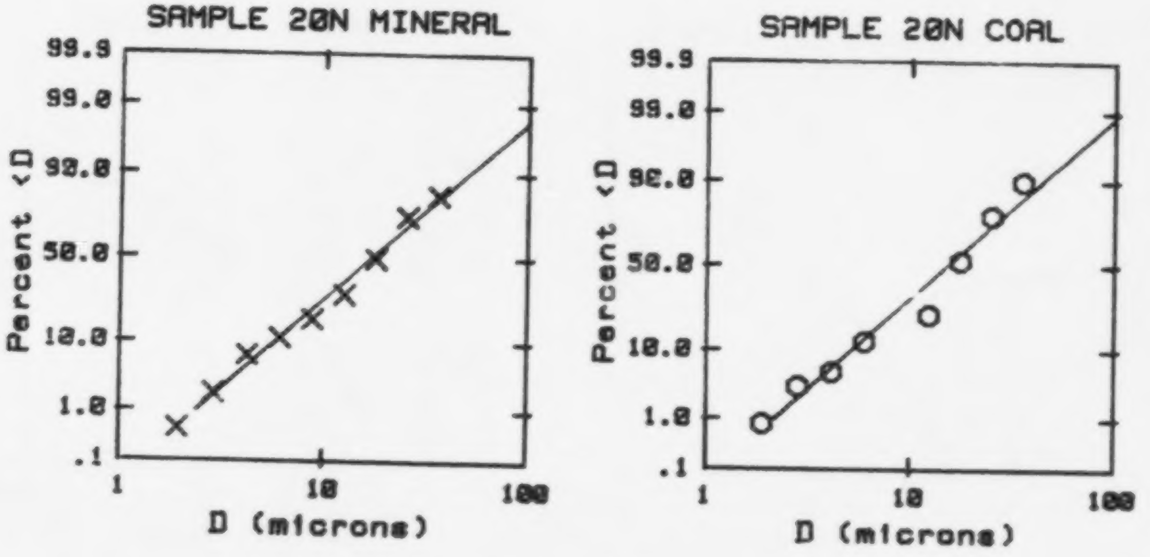
0.5 Meter Elevation

Figure 6. Cumulative mass distributions for mineral and coal particles sampled at two elevations on August 1, 1979.


SAMPLE 17N MINERAL

SAMPLE 17N COAL

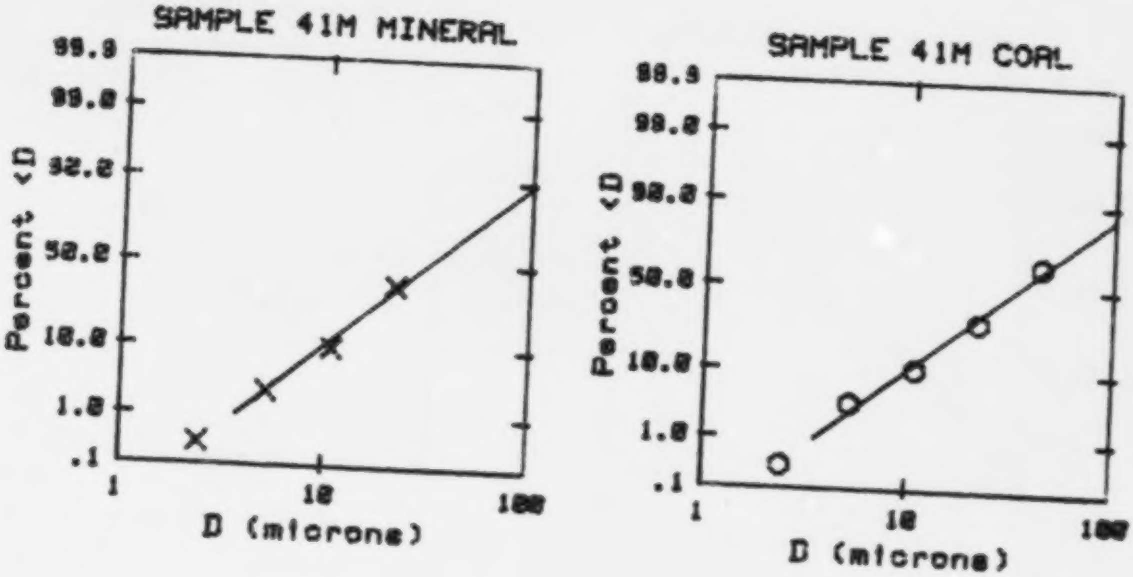
75 Meter Elevation


SAMPLE 20N MINERAL

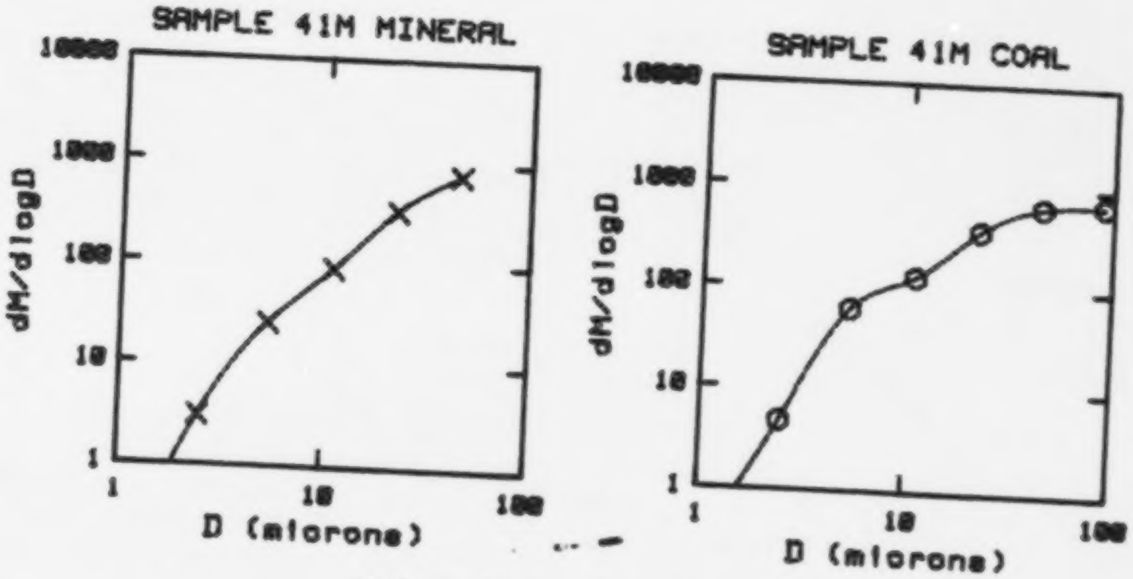
SAMPLE 20N COAL

0.5 Meter Elevation

Figure 7. Cumulative mass distributions for mineral and coal particles sampled at two elevations on August 5, 1979.



Cumulative Mass Distributions



Differential Mass Distributions

Figure 8. Cumulative and differential mass distributions of mineral and coal particles sampled at an elevation of 30 meters on August 6, 1979.

Table 1. Sampling Results

Date	Filter Number	Sampling Elevation (m)	Total Particles Counted		d_{gm} (µm)		σ_g	
			Mineral	Coal	Mineral	Coal	Mineral	Coal
8/1/79[a]	5N	75	438	221	15.4	13.8	2.42	2.21
	6N	20	414	165	17.7	17.3	2.27	2.34
	7N	10	327	234	18.1	21.1	2.40	2.60
	8N	0.5	262	137	24.4	28.2	2.59	2.61
8/5/79[b]	17N	75	523	283	10.6	13.2	2.33	2.60
	20N	0.5	382	130	17.1	15.5	2.33	2.30
8/6/79[c]	41M	30	138	523	32.2	34.5	2.51	2.64

[a] Mine operation: hauling, dragline, dressing, scraping.
[b] Mine operation: dragline only.
[c] Mine operation: hauling only.

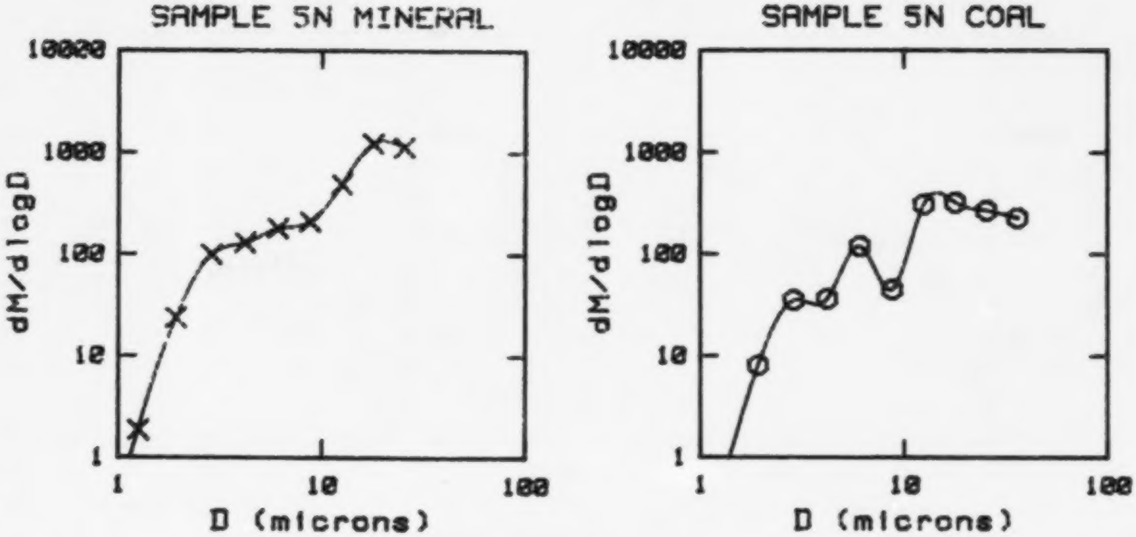
For samples 5N through 8N collected on August 1, in which the mine operations consisted of coal hauling, dragline overburden removal, dressing and topsoil scraping, d_{gm} values for both mineral and coal particles are reported in the table to be highest at ground level (0.5 m elevation) and successively decrease, as would be expected, for samples taken at elevations of 10, 20 and 75 meters. The vertical profile of d_{gm} for mineral and coal particles sampled on August 1 appears to follow an exponential type relationship. For samples 17N and 20N collected on August 5 (at the same balloon launch location as that of August 1), during which time the only mine operation was overburden removal by the dragline, d_{gm} values are again highest for the ground level sample versus the 75 meter sample. The ground level d_{gm} values for mineral and coal on August 5 are considerably less than those of August 1 but this is reasonable when one considers, besides the reduced mining activities, that the topsoil scraping operation of August 1 occurred approximately 100 m closer to the balloon launch site. The fact that coal particles were present in concentrations comparable to the mineral particles on the August 5th samples is interesting. The source of this coal may have been the pit itself, assuming that the dragline was removing overburden near the coal seam, or from the storage coal pile.

Dust from a haul road was monitored only at an elevation of 30 m on August 6 (sample 41M). The sampling occurred at a considerably shorter downwind distance from the source than on either August 1 or August 5 (see Figure 2). Here d_{gm} values for mineral and coal are significantly greater at the 30 m elevation than those measured at ground level on the previously reported sampling days. In addition, the total number of coal particles observed on the 41M micrographs was almost four times the number of mineral particles. This is probably because some coal often spilled from the haul trucks at the haul road curve. This coal would become crushed and entrained into the air by trucks passing by later. In all instances, d_{gm} values of mineral versus coal are comparable at the same elevations.

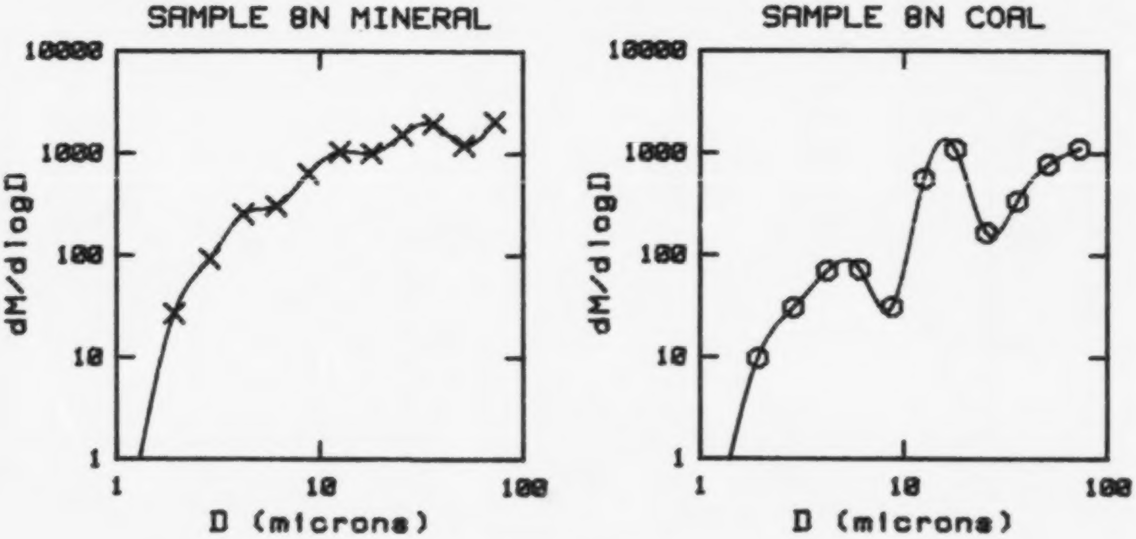
The average of all geometric standard deviations reported in Table 1 is 2.43 with a corresponding "standard deviation" of 0.14. This shows good agreement in the data such that all of the samples are believed to be from the same general population of particles.

All of the cumulative mass distribution plots of Figures 6, 7 and 8 show a characteristic inflection point in the vicinity of particle diameters from 10 to 15 μm. This may be attributable to the fact that the 80x and 640x magnifications were sufficiently far apart that minimal overlap occurred in the area where the two magnifications were least accurate.

Differential mass distributions for the sampled mineral and coal particles are presented in Figures 8, 9 and 10. The graphs are log-log plots of the mass per interval divided by the difference of the log D interval boundaries ($\mu g/m^3$) versus particle diameter (μm). The data points have been joined by smooth curves using a spline fit routine. It is apparent that the mineral plots are more well behaved than the coal

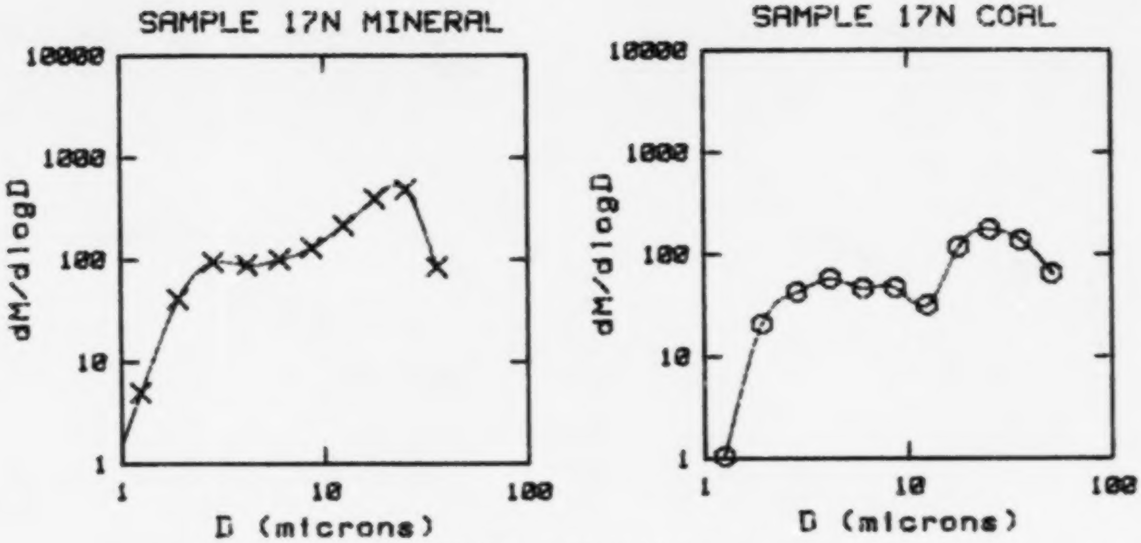


75 Meter Elevation

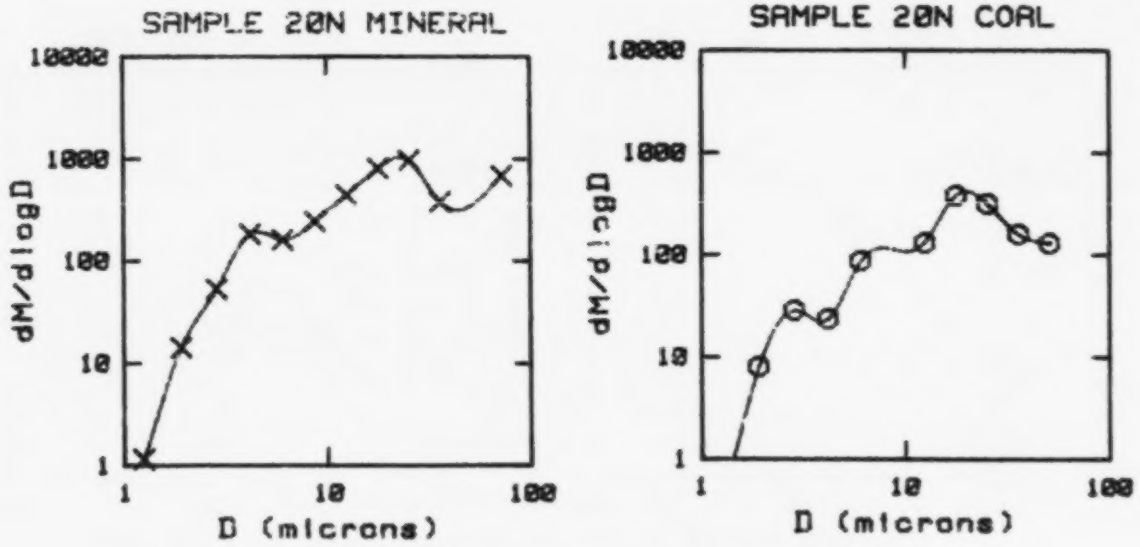


0.5 Meter Elevation

Figure 9. Differential mass distributions for mineral and coal particles sampled at two elevations on August 1, 1979. (The unit of the ordinate axis is $\mu g/m^3$).



75 Meter Elevation



0.5 Meter Elevation

Figure 10. Differential mass distributions for mineral and coal particles sampled at two elevations on August 5, 1979. (The unit of the ordinate axis is μg/m^3).

plots. This can be attributed to the fact that in general, except for sample 41M, 50 percent fewer coal particles were observed on the micrographs compared to mineral particles. The distributions show that the majority of mass for both mineral and coal sampled at any elevation is associated with the larger particles. Note that tethered balloon sampling was conducted with open faced filters such that nonisokinetic sampling took place in which the filter face velocity was normally considerably less than the mean wind speed. This has undoubtedly biased the samples to some extent with large particles. Still, as expected, the vast majority of the captured dust particles from the mining activities were in a coarse size range of greater than 2 μm in actual diameter for all samples.

Soil Sample Analysis

To determine the major crystalline mineral composition of the selected soil samples, each sample was first pulverized, by means of a ball mill, to fine material which would pass through a 200 mesh screen. The powder samples were then semiquantitatively analyzed by a Philips X-ray Diffractometer. Diffraction spectra were obtained using copper $k\alpha$ x-rays from 2° to 64° 2θ. Minerals were identified by peak position and semiquantified by comparing peak intensities to those of other known mineral samples. The results of this analysis are presented in Table 2.

Time Lapse Movie Analysis

Time lapse movies have been analyzed to confirm the downwind distances of the tethered balloon sampling system from mining operations and to establish the types and levels of activities occurring at the mine site during sampling. An example of the information obtained concerning mine operations for one day is presented in Table 3. The time lapse photography was also useful in documenting the relative amount and vertical extent of dust from the various mine operations and in qualitatively assessing the effectiveness of watering to suppress dust from active haul roads. During hot dry afternoons, haul road watering markedly reduced the amount of visible dust from the roads for periods of 30 to 40 minutes.

CONCLUSIONS

The tethered balloon sampling method, coupled with microanalysis, can provide useful definitive insights into the nature of multispecied, size discriminate particulate dispersions from fugitive dust sources. The sampling method permits rapid horizontal and vertical mobility and simultaneous sample collection at selected elevations and distances downwind from dust sources with relatively little expense. Optical and electron microscopy provides useful estimates of particle size distributions, concentrations and composition of lightly loaded samples. This investigation concludes that the tethered balloon sampling method can extend the exposure profiling technique to more fugitive source sampling applications.

Dust samples collected from the plumes of various strip mine operations follow a log-normal distribution. Sampling at various elevations downwind

Table 3. Mine Site Activities on July 31, 1979

Time of day (hrs)	Wind Dir. from	Dragline Operation	Topsoil Scraping Operation: Number of Scraper Passes	Topsoil Scraping Operation: Time of Watering Trucks	E-W Haul Road Lg. Truck Traffic: Number of Haul Truck Passes	E-W Haul Road Lg. Truck Traffic: Time of Watering Trucks	Other Activities	Remarks
0730								0745 Start of balloon sampling operation
0800								
	W	0836 up	6	0855	17		0836-0842 Cat dressed crushed coal pile	0836 Start of time lapse movie-Roll 2
0900		0936 down	13	0942	30		0836-1140 Coal loading south end of pit A	Winds light all day steady from W until 1155 then extremely variable
1000		1010 walk 1030 up	30	1029	36		0934-1006 Cat dressed dragline base area Charge drill rig in operation all morning	Balloon samples taken near CSU stakes 17 & 18
1100	E	1123 down	28	1114	29		Cat dressed south end of O.B. pile (W of D.L.) all morning 0836-1045 1136-1216 Cat dressed O.B. drill area (E of D.L.)	
1200	W		—		2			1216 End of Roll 2
								1232 Start of Roll 3
	E W N	1232 up	—		11		1232-1548 Cat dressed O.B. pile (W of D.L.)	
1300	E W E		16	1348	15	1311 1323 1352 1356	1331 Coal blast in Pit A 1232-1659 Cat dressed O.B. drill area (E of D.L.)	1321 Clock blown over-event times calc. from frame #
1400	W E W E		22	1426	23	1409 1413 1434 1445 1451 1454	Charge drill rig in operation all afternoon	1412 End of balloon sampling operation
1500	W E		16	1506 1553	26	1515 1518 1531	1405 to end coal loading south end of Pit A 1232-1300 1405-1558 1625-1700 Cat dressed D.L. base area	
1600	W E		28	1648	33	1633 1652 1658	1658 O.B. blast	1659 End of Roll 3
1700								
Total Number of Passes			159	9	222	16		

Table 2. Soil Sample Analysis

Mineral	Sample Composition[a]		
	Haul Road	Drill Hole Spoils	Overburden Pile
Quartz	Major	Major	Major
Feldspars	Minor	Major	Minor
Dolomite	Trace	Major	Minor
Calcite	Trace	Minor	Minor
Kaolinite	--	Trace	Trace
Plagioclase Feldspar	Trace	Trace	Trace
Montmorillonite	--	--	--

[a] Major - $\geq$ 25% of sample.
Minor - distinct portion of sample (5-25%).
Trace - slight peak present (~ < 5%).
-- - absent from sample (~ < 1%).

of mining activities has demonstrated that the mass media diameters of mineral and coal particles decrease with increasing sampling height. Still, considerable dust concentrations are present at a sampling height of 75 m and a significant fraction of this dust consists of particles having diameters greater than 10 µm. The large particles are responsible for the major mass fraction of all samples.

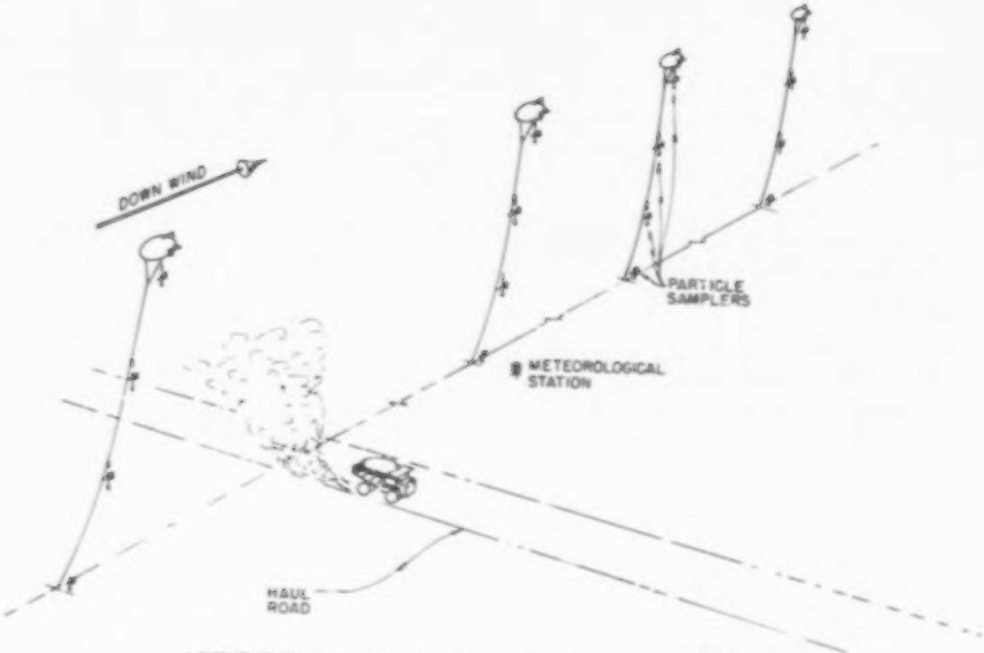
Time lapse photography has been shown to be a useful technique to document balloon sampling operations and surface mining activities. This technique can be applied to visually assess the effectiveness of dust control measures and strategies.

PLANNED ACTIVITIES

Tethered balloon sampling at higher elevations and over a wider range of downwind distances will be conducted at surface mines to more accurately determine the vertical extent and downwind transport of fugitive dust plumes.

A series of balloon systems will be utilized in conjunction with the exposure profiling technique to establish improved emission factors from mining and other fugitive emission sources. Typical sampling schemes employing four balloons are presented in Figures 11 and 12. When sampling a line source, such as the haul road shown in Figure 11, it is envisioned that the three downwind balloons will be aligned parallel to the prevailing wind. This network will allow the downwind dust transport to be evaluated as well as the validity of extending the exposure profile technique to greater sampling distances. The characterization of emissions from point and area sources will require a two dimensional sampling network, such as that shown in Figure 12. As with the line source sampling scheme, an upwind balloon will be operated to determine background dust concentrations.

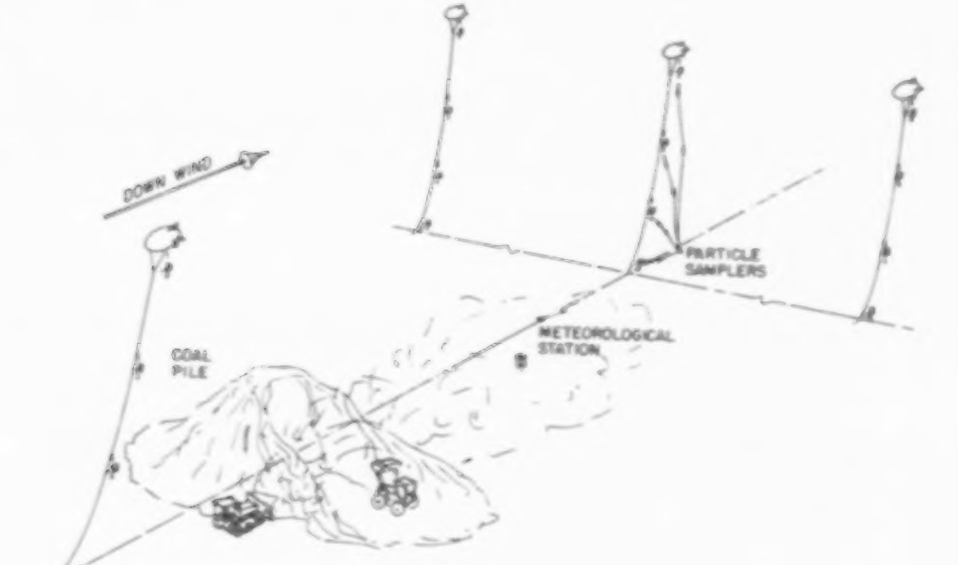
Basic improvements to the wind vane particle samplers are also planned. Elutriators will be added to the samplers to allow for the sampling of inhalable particles having an aerodynamic diameter of 15 µm or less.[10] Inhalable particles can further be subdivided into groups of coarse and fine fractions with a cut point being approximately 2.5 µm. The fine particles are primarily responsible for air quality visibility degradation and are primarily produced by combustion processes. The coarse fraction of inhalable particles are those between 2.5 and 15 µm and are normally classified as mechanically generated. Most wind generated dust, for example, would consist of coarse size particles. Depending on the type of source being sampled, it may sometimes be desirable to be able to separate inhalable particles into coarse and fine fractions. For example, fugitive particulate emissions from an iron foundry are expected to be a mix of fine and coarse particles. By being able to quantify the fractions in terms of amount and chemical composition, the actual emission sources should be able to be identified. When desired, the balloon samplers will employ sequential filtration to separate inhalable particles into coarse and fine fractions.[11]



DOWN WIND
PARTICLE SAMPLERS
METEOROLOGICAL STATION
HAUL ROAD

LAYOUT OF TETHERED BALLOON SAMPLING SYSTEM FOR PROFILING THE PLUME FROM A LINE SOURCE AND FOR DETERMINING THE DOWNWIND TRANSPORT OF PARTICLES.

Figure 11



DOWN WIND
PARTICLE SAMPLERS
METEOROLOGICAL STATION
COAL PILE

LAYOUT OF TETHERED BALLOON SAMPLING SYSTEM FOR PROFILING THE PLUME FROM AN AREA SOURCE.

Figure 12

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Appendix A. Sampling Log of Selected Balloon Operations

Date	Filter Number	Sampling Elevation (m)	Start Time (hrs-MDT)	Total Time (min)	Air Vol. Sampled (ℓ)	Remarks
8/1/79	05N	75	0659	283	778	
	06N	20	0708	269	740	
	07N	10	0711	264	317	
	08N	0.5	0720	263	421	
8/5/79	17N	75	0828	408	1122	
	18N	20	0830	?	?	Pump stalled during sampling
	19N	10	0835	265	318	
	20N	0.5	0848	372	595	
8/6/79	41M	30	1155	165	553	

Note: Launch sites shown on Figure 2.

PARTICLE PRODUCTION FROM SURFACE MINING: PART 2

SURFACE PARTICULATE AND METEOROLOGICAL MEASUREMENTS

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Federal land managers are now being challenged to evaluate the scope of potential environmental effects in the development of western mineral resources. The influence that surface mining for coal will have on air quality is one impact that must be considered. This paper describes the first phase (summer 1979) of a study to investigate the sources, characteristics, and transport of particulate emissions from surface mining. Air quality and meteorological measurements were made on a surface mine in western Colorado. Near source suspended and deposited particulate loads were quantified as they relate to meteorological conditions and mining operations. The results characterize the variety, variability, and complexity of particulate emissions from mining operations in the western states. The study provides the basis for a continued research effort (Phase II) to be conducted in the summer of 1980.

INTRODUCTION

There is an increasing demand for coal in the United States. A large portion of our coal reserves exist on federally managed land in the semi-arid regions of the western states. Federal land managers are now being challenged to evaluate the scope of potential environmental effects in the leasing and development of these western energy resources. The influence that surface mining for coal will have on air quality is one impact that must be considered.

Most air quality regulations that apply to surface mining are still unresolved. The Environmental Protection Agency (EPA) has proposed regulatory procedures (44 FR 51924, September 5, 1979) that alter their previous exclusion of fugitive dust from prevention of significant deterioration (PSD) review. Fugitive dust is defined as particles of native soil uncontaminated by pollutants resulting from industrial activity. The proposed EPA procedures now state that fugitive emissions should not be considered in determining air quality degradation except for 26 named source types. The procedures also state that the Administrator of the EPA will consider the need for additional source types, including surface mining, over the next few months. However, even when fugitive dusts are excluded they cannot be ignored. Proposed regulations point out that: 1) the applicant must determine the amount of total emissions that are fugitive dust; 2) mines emitting greater than 250 tons/year (225 metric tons/year) including fugitive dust must apply best available control technology; and 3) the fugitive dust exclusion will be reviewed periodically by the EPA. In addition to EPA regulations, the Office of Surface Mines and most states also consider air quality in their regulations.

Despite these regulatory clarifications and exemptions, the federal land manager remains challenged with making environmentally sound, resource related decisions. These decisions may be affected by the lack of knowledge about the sources, nature of particles, and transport of all emissions from surface mining, including fugitive dust.

The purpose of this study is to conduct field research on the sources, nature of particles and transport of air pollutants from surface mining. The study is funded by the Bureau of Land Management and is being performed in combined effort by the U.S.D.A. Forest Service, Rocky Mountain Forest and Range Experiment Station and Colorado State University. The broad goal of the study is to provide insights into the nature and magnitude of air quality impacts that federal land managers must consider. The study is being conducted in two phases over a two year period. Phase I, performed during the summer of 1979, emphasized near-source analysis of surface mine emissions from a test site in western Colorado. Phase II, to be conducted in 1980, will emphasize analysis of air quality at various upwind and downwind distances from the surface mine. This paper discusses the preliminary results from the Phase I field program.

BACKGROUND

In most of the non-industrialized arid west, air quality and visibility are dependent on the amount of native or fugitive dust in the air. The dust is emitted by human activity and wind erosion of undisturbed and disturbed lands. The more people, agriculture, mining or other activity, the greater the amount of dust released into the atmosphere. In addition, the increasing number of industrial sources, such as coal fired power plants and mineral processing facilities, is influencing air quality. What, if any, contribution surface mining emissions have on local or regional air quality can not be easily determined. The wide variety of pollutant sources associated with mining areas such as mine mouth power plants, boom-town growth, and increased traffic make isolating the pollutant contribution of a surface mine even more difficult. Measurement techniques to quantify and separate each of these sources to evaluate their respective impacts are limited, varied, and complicated.

This study was not designed to address or answer all of the air quality problems of the west, but was designed with four major objectives:

1. determine the sources and quantity of particulate emissions from surface mining;
2. determine the physical and chemical nature of the emissions;
3. determine the background particle loading, deposition, and visibility in semi-arid regions of the west; and
4. develop and validate various particle sampling technologies.

The overall goal in addressing these objectives is to provide information related to the decisions federal land managers face in leasing and managing our nation's mineral-rich western land.

To accomplish these objectives, a two phase field program was developed. Phase I, conducted during the summer of 1979, emphasized the characterization of particulate emissions near the broad range of sources in a surface mining operation. Field measurements were taken on an active surface mine during two periods (June 4-7 and July 30-August 7, 1979). Along with the measurements taken by the Colorado State University/Rocky Mountain Forest and Range Experiment Station team, the study site was shared with independently supported research teams from the Denver Research Institute and the University of Minnesota. In addition to the on-site mine activities, Phase I work also established an atmospheric deposition station and a visibility monitoring station. The deposition station is operated as part of the National Atmospheric Deposition Network. Visibility measurements will be used in analyses that will attempt to consider the effects of fugitive emissions on atmospheric visibility.

Phase II, to be conducted during the summer of 1980, will emphasize the measurement of atmospheric particulate loading at increased upwind and downwind distances from the surface mine. The measurements from both phases will be combined and applied to evaluate transport mechanisms and to estimate what, if any, effect particulate contribution from mining may have on local and regional air quality.

PHASE I FIELD PROGRAM

The Study Site

A fully operational surface coal mine served as the study site. All associated mining activities cover an area of approximately four square miles (10.3 km^2). The topography of the region is rolling terrain with an average elevation of approximately 6,500 feet (1,980 m). The mine was located on a gentle, north facing slope.

Weather plays a major role in the emission and transport of fugitive dust in the arid west. The study site is located in a region that receives a yearly average of 13.5 inches (34 cm) of precipitation. Precipitation is distributed evenly throughout the year. Winters are cold and windy and light snow cover is often present. In the summer months, intense solar radiation, persistant winds and low relative humidity contribute to hot and dry conditions, providing an environment for maximum fugitive dust emissions.

Land use in the region includes dryland agriculture (primarily winter wheat) and livestock grazing. Native vegetation is sparse and dominated by sagebrush.

Particulate Sources

The sources of particulate emissions from the mine include:

- dragline operation
- coal loading in pit
- drilling
- overburden blasting
- coal seam blasting
- top soil scraping
- grading
- haul road traffic
- coal storage pile dressing
- coal crushing (only during June 4-7)
- loading from storage pile

The emissions generated from each source are dependent on wind speed, moisture, type of equipment, and scheduled time of the activity. The nature and strength of the source can be affected by a wide range of circumstances. For example, a haul truck that is slightly overloaded can spill a portion of its load while rounding a corner. Subsequent haul trucks will crush and entrain the spilled coal into the atmosphere. Under these circumstances, a haul road, normally a source of primarily fugitive dust, will become a source of coal particulates until a road grader cleans and dresses the haul road. With these intricate variations in sources and source strength, isolating individual particulate sources in an operating coal mine is extremely difficult. Therefore, throughout the analysis of Phase I data, no attempt was made to calculate the emission factor of any individual particulate source.

Two short-term field programs were conducted during the summer of 1979 (July 4-7 and July 30-August 7). Hot, dry, and often windy conditions coupled with all mining operations being in full swing provided an environment where maximum particulate emissions could be expected. If measurements were taken in the winter or wet spring, very different results would be expected.

Instrumentation

The need to measure particulate emissions from complicated area sources such as a surface mine has stimulated the technical imaginations of many a researcher. The instrumentation used in Phase I employed both standard and imaginative technology. The primary sampling strategies used on the mine site included active and passive particulate measurements and meteorological measurements. Off-site measurements were taken of atmospheric deposition and visibility. Though associated with the study, these off-site measurements are also committed to other research goals.

Active Particulate Samplers

1. High Volume Samplers: Two high volume samplers (hi-vols) were operated during both Phase I field programs. The hi-vols were located approximately 100 and 150 meters from a major particulate source area. For the June program, the hi-vols were operated with standard filters. During the July-August program, the hi-vols were outfitted with Andersen Head particle size samplers in order to obtain information about the particle sizes contributing to the near source air quality. Due to the location of the hi-vols, the particulate loading they monitored was probably dominated by haul road traffic and coal storage pile activities. A schematic showing the location of the hi-vols and other on-site instrumentation relative to the location of mining activities is presented as Figure 1.

2. Wind Erosion Threshold Velocity Measurements: As part of the June sampling program, a portable wind tunnel, operated by Dr. Dale Gillette (National Center for Atmospheric Research), was used to determine the threshold wind velocities required to erode a variety of surfaces. Analyses were performed over freshly dressed and weathered coal storage piles, dry and wetted haul roads, wheat fields, spoil piles, graded reclamation areas, native cover, and other surfaces. Analysis of the data will highlight the erodability of various stages of disturbed land and coal storage as compared to undisturbed and agricultural land.

3. Elemental Analysis: As part of the July-August sampling program, a spatial and temporal variety of particulate samples were taken by Dr. Thomas Cahill (University of California, Davis) for elemental analysis. Samples taken both upwind and downwind from the mine will be analyzed for their chemical and physical characteristics.

4. Balloon-Borne Particulate Samples: In a separate project, Dr. James Armstrong and his associates from the Denver Research Institute collected particulate samples throughout the study area via a balloon-borne sampler. The results of their research are presented in the preceding paper of this symposium.

5. University of Minnesota Mobile Laboratory: During the summer of 1979, Dr. Virgil A. Marple and his associates were conducting air quality experiments throughout the southwest as part of the U. S. Environmental Protection Agency VISTTA visibility research program. In support of both EPA and Bureau of Mines funding, the University of Minnesota took advantage of the July-August sample

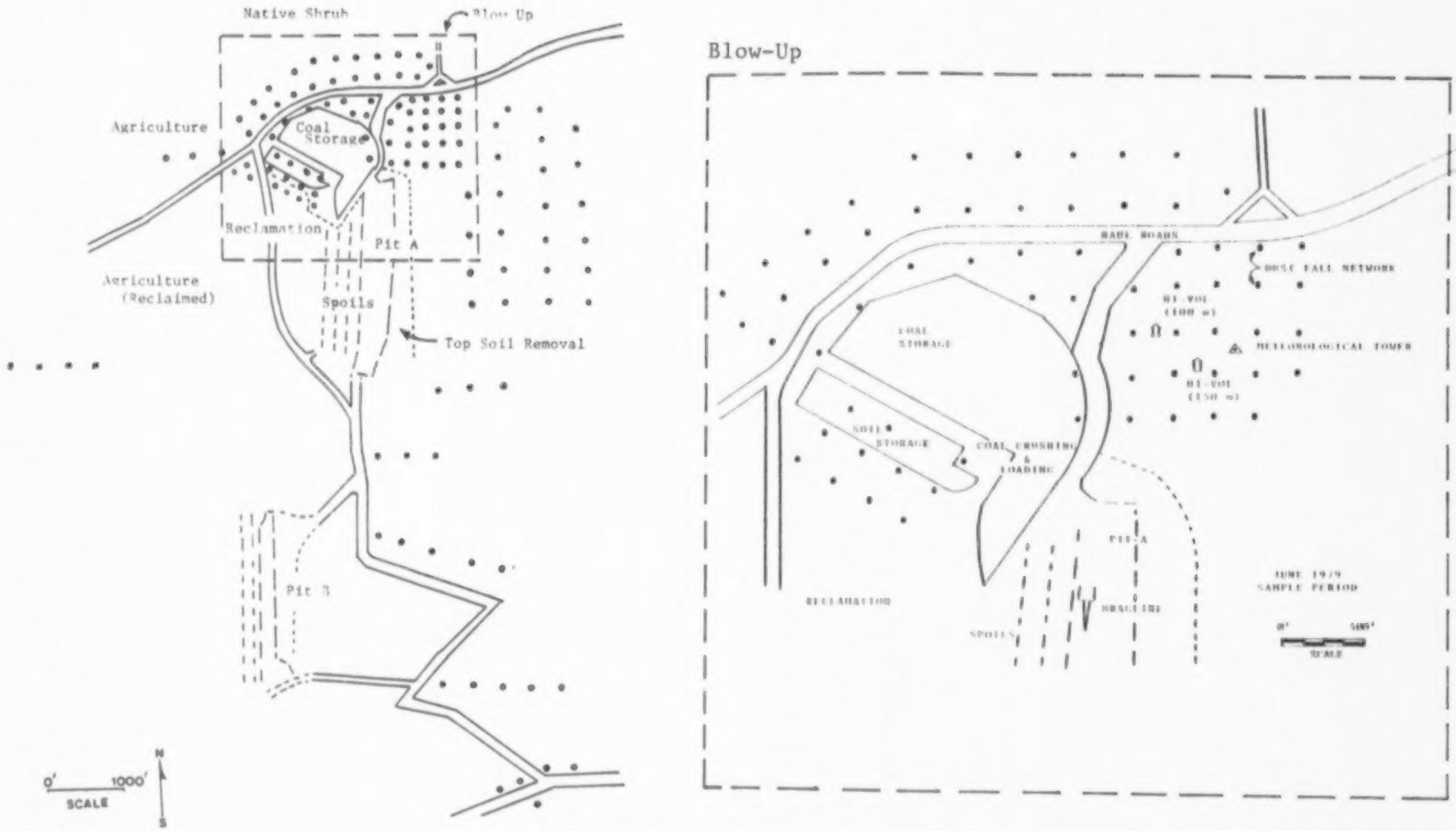
Native Shrub
Blow Up
Agriculture
Coal Storage
Reclamation
Pit A
Agriculture (Reclaimed)
Spoils
Top Soil Removal
Pit 3
0' 1000' SCALE
N
S
Blow-Up
HAUL ROADS
DUST FALL NETWORK
HI-VOL (100 m)
COAL STORAGE
METEOROLOGICAL TOWER
HI-VOL (150 m)
SOIL STORAGE
COAL CRUSHING & LOADING
PIT A
JUNE 1979 SAMPLE PERIOD
RECLAMATION
DRAGLINE
SPOILS
0' 500' SCALE

FIGURE 1

LOCATION OF INSTRUMENTATION AND MINING ACTIVITIES period to investigate surface mine emissions. The instrumentation in the mobile laboratory was capable of making fast response measurements of the chemical and physical nature of particles, particle transport and visibility. The mobile laboratory permitted specific monitoring of individual emission sources.

Passive Particulate Samples

1. Petri Dish Dust Fall Network: Dust fall collectors were fabricated for the study. Each collector consisted of a standard petri dish equipped with a dust catchment media (astroturf). Each dish was mounted at 0.5 meters above the soil. Dust fall was collected over a one day period in June and over two four-day periods in the July-August program. Collected dust fall was weighed and converted to dust fall rates (g/m^2 day). Dust fall samples were also qualitatively analyzed for the amount of coal, and, during the June field program, for presence of seeded tracer material.

A 60 dish network was established for the June field program. The distance between dishes was approximately 60 meters. The network was expanded to 120 collection sites for the July-August program.

Meteorological Measurements

1. Tethersonde: A tethered helium balloon with an instrument package was used to measure verticle profiles of wind, temperature, and humidity. These soundings were generally taken three times per day (early morning, noon and early evening). On the average, the soundings extended from the surface to 450 meters.

2. MRI Weather Stations: Wind speed, wind direction and temperature were monitored continually by MRI weather stations. One station was located near the meteorological tower and within the dust fall network. Measurements taken at this station are representative of the local meteorology within the major sampling area. A second MRI station was located at a topographic high point overlooking the mine and was considered more representative of the synoptic flow.

3. Atmospheric Turbulence Measurements: A 15 meter tower was erected near the center of the data collection activities. Three sets of Gill (u,v,w) anemometers were placed at heights 1, 3, and 15 meters on the tower. The instrumentation was connected to an automatic data logging system that recorded instantaneous signals from the anemometers for 2.5 minutes each hour (at a rate of three scans per second). The data will be used to evaluate the nature of atmospheric turbulence at the field site.

Off-Site Instrumentation

1. Atmospheric Visibility Site: Daily visibility measurements started in April 1979 and continue to date. Two different instruments are used, a contrast telephotometer and an integrating nephelometer. The visibility site overlooks the mine and is located on a hill top approximatly ten kilometers from the mine site. The telephotometer is aimed at four different distance targets once each day at mid-morning. The mine site is located between the telephotometer and one of these targets. The nephelometer runs continuously sampling local air.

RESULTS AND DISCUSSION

Preliminary results from the first phase (summer 1979) highlight a number of interesting observations pertaining to the sources, nature, and transport of fugitive emissions from surface mining. Emission sources at the mine included a complex array of point, line, and area sources. The primary study area concentrated on emissions generated in the vicinity of the pit and coal storage pile. A primary haul road in this vicinity appeared to be a major contributor to the particulate loading of the local atmosphere. The following observations and results were recorded by the various instrumentation utilized in the June and July-August sample periods of Phase I.

Active Particulate Samples

High volume sampler results indicate that the total suspended particulate concentrations, near the mining and coal handling operations were quite high (200 - 1000 $\mu g/m^3$) and well above the background (annual average approximately 40 $\mu g/m^3$). However, indications are that groundlevel air concentrations decrease rapidly downwind from the sources. Due to the location of the hi-vols and frequency of wind direction, the majority of the dust collected by the hi-vols was probably generated from coal storage pile and haul road activities. On the average, total suspended particulates measured at the hi-vol located 150 meters from the haul road and edge of the coal storage were 33 percent less than measured at 100 meters. During the July-August sampling periods, Andersen Head particle sizing plates were operated on the hi-vols to provide information on the particle size distribution of the suspended particulate loads. Results indicate that approximately 35 percent (be weight) of the particles sampled were above 7 µm and 35 percent (by weight) of the particles were below 1 µm.* Table 1 presents the hi-vol measurements for the July-August sample periods. Figure 2 presents a representative sample (August 6-7 measurement) of Andersen Head particle size distributions.

Analyses of the wind erosion threshold velocity measurements and elemental analysis are continuing. Therefore, the results are not available for this report.

Passive Particulate Samples

The dust fall network provided the opportunity to observe how deposition rates vary with distance from the mining operations. Rates as high as 25 g/m^2-day were recorded immediately adjacent to haul roads, but usually within 600 meters of a source the rates had dropped to less than 1 g/m^2-day. Topography, meteorology, and mining activity had an effect on the deposition pattern. An example plot of dust fall rates for the July 30-August 3 period is presented as Figure 3. In addition to total dust fall two other qualitative analyses were performed on the dust fall samples. The amount of coal in the dust fall sample relative to the amount of non coal dust was estimated for each sample. Results indicated that coal amounts were highest around the coal storage pile, near a haul road turn where coal was being spilled from haul trucks, and immediately downwind from the pit (perhaps due to coal seam

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*It should be pointed out that size separation was accomplished using the standard hi-vol sampler. No 15 µm cyclone cut-off device was used; therefore the sample may be somewhat biased to the smaller particle sizes.

TABLE 1
HI-VOL RESULTS
(24 Hour Samples at 1200 MDT)

Date	LOCATION (meters from major sources)	Particulate Concentrations in $\mu g/m^3$ and Percent					
		Anderson Head Results (Plate No. and 50% Cutoff Dia. in µm)					Total Particulates
		1-1 (7 µm)	2-3 (3.3 µm)	3-4 (2.0 µm)	4-5 (1.1 µm)	Back-up (<1 µm)	
7/30-7/31	150	-	-	-	-	-	Equip. Fail.
	100	-	-	-	-	-	Equip. Fail.
7/31-8/1	150	-	-	-	-	-	Equip. Fail.
	100	176	51	29	23	153	432
		(40.7)	(11.8)	(6.7)	(5.4)	(35.4)	
8/1-8/2	150	-	-	-	-	-	262
	100	84	43	33	14	259	433
		(19.4)	(9.9)	(7.6)	(3.3)	(59.8)	
8/3-8/4	150	199	65	46	28	145	483
		(41.2)	(13.5)	(9.5)	(5.8)	(30.0)	
	100	-	-	-	-	-	916
8/4-8/5	150	113	39	33	22	70	277
		(40.8)	(14.1)	(11.9)	(7.9)	(25.3)	
	100	197	78	58	44	247	624
		(31.6)	(12.5)	(9.3)	(7.0)	(39.6)	
8/5-8/6	150	77	29	25	10	62	203
		(37.9)	(14.3)	(12.4)	(4.9)	(30.5)	
	100	102	43	23	13	234	415
		(24.6)	(10.4)	(5.5)	(3.1)	(56.4)	
8/6-8/7	150	191	54	48	25	56	374
		(51.1)	(14.4)	(12.8)	(6.7)	(15.0)	
	100	264	93	78	44	244	723
		(36.5)	(12.9)	(10.8)	(6.1)	(33.7)	

FIGURE 2
SURFACE MINE EMISSION STUDY

HI-VOL SUSPENDED PARTICULATE CONCENTRATIONS
AND ANDERSON HEAD PARTICLE SIZE

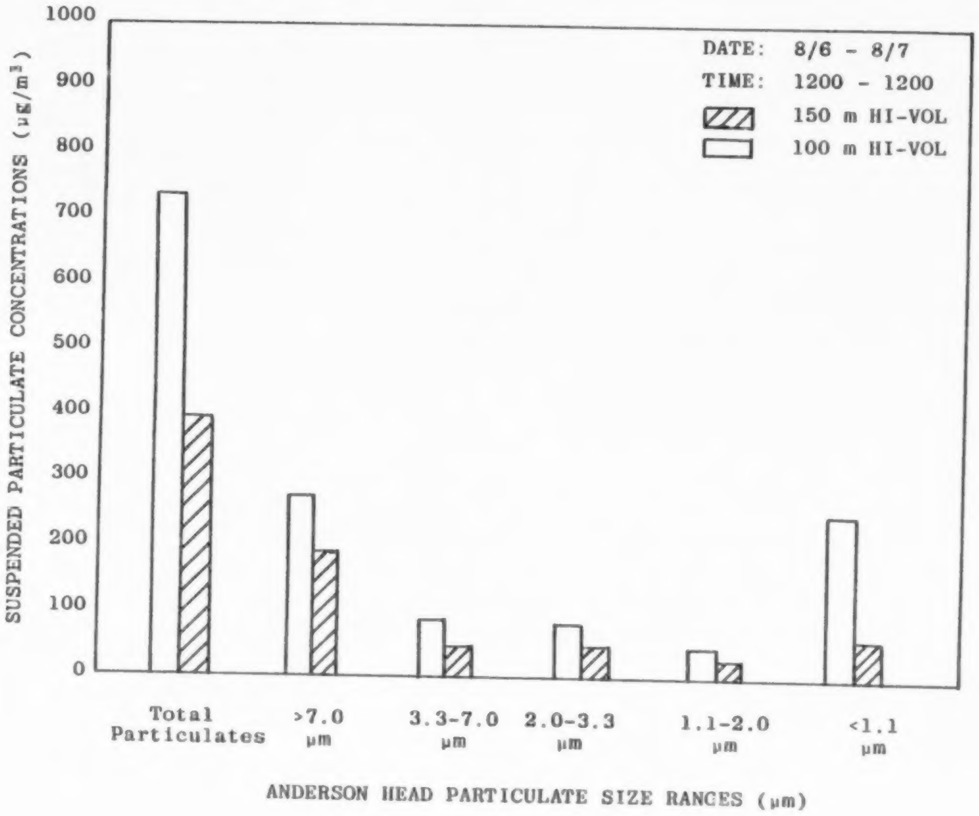
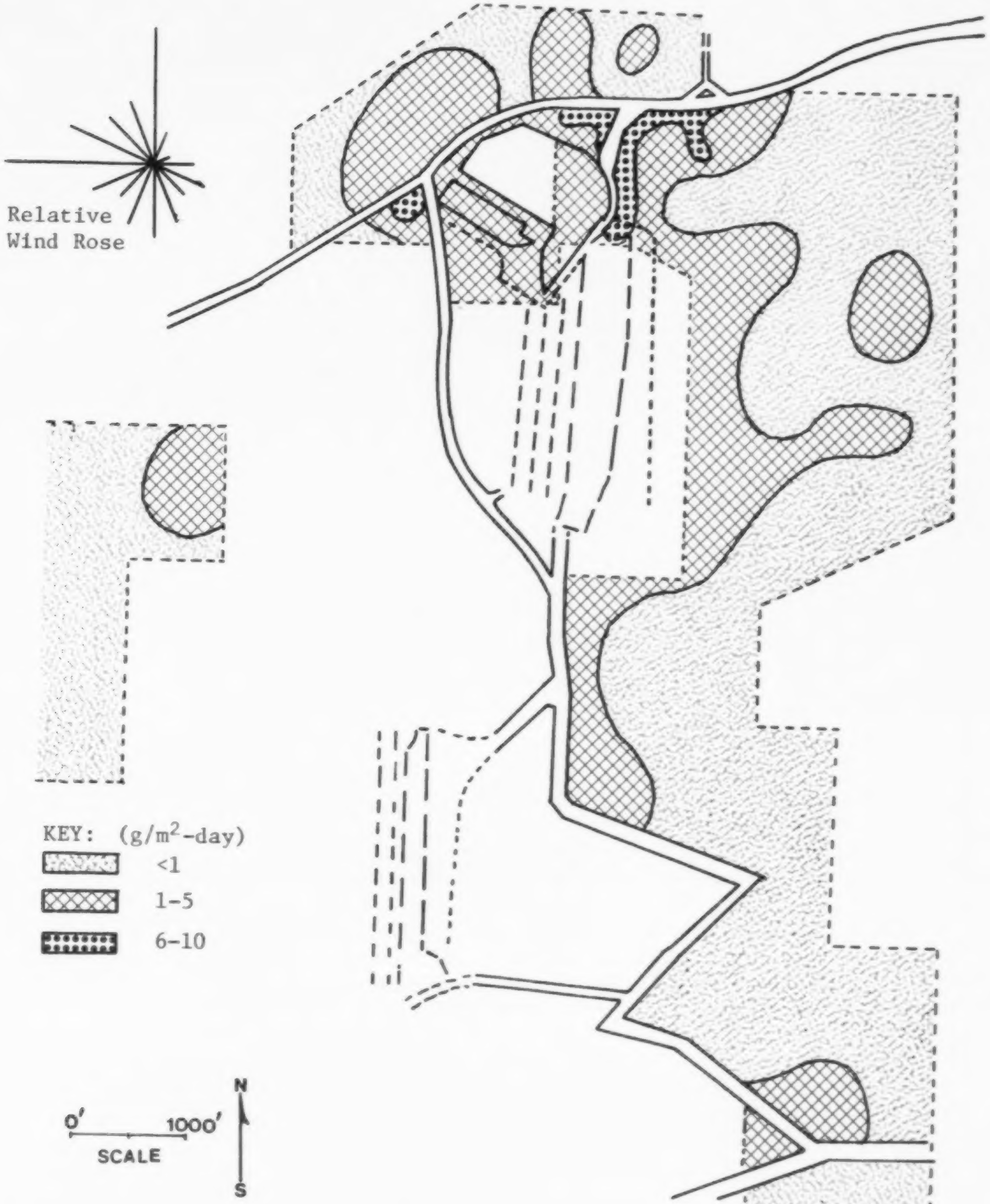


FIGURE 3

DUST FALL DISTRIBUTION
7/30/79 - 8/3/79


Relative
Wind Rose
KEY: (g/m^2-day)
<1
1-5
6-10
0'
1000'
SCALE
N
S

blasting). A plot of the amount of coal in the dust fall samples for the July 30-August 3 period is presented as Figure 4.

During the June sampling period coal haul roads were seeded periodically with a florescent particle tracer. When a truck would pass over the haul road the particles would become entrained and later fall out on the dust fall network. The amount of tracer material found in the dust fall samples during analysis correlated well with the wind direction. The tracer provided confidence that the dust fall network was sampling material generated from mining activities.

Meteorology Measurements

Daily wind roses were plotted throughout the sample periods. Daytime winds were predominantly from the west and northwest. The orientation of the topography appeared to channel the synoptic flow into westerly local flow at the study site. Strong, gusty winds often occurred between 1400 and 1600, induced by local thermal convective cells. At night, a downslope (southerly flow) was often established. Inversions occurred on most mornings and were usually broken by 11:00 a.m. The tethersonde soundings effectively illustrated a number of these inversions. Figure 5 provides an example of soundings at 7:00 and 12:00 on August 6. Throughout the study periods, a number of dust devils were observed. These mini-cyclones would entrain and carry particulates to altitudes of hundreds of meters.

Air turbulence data taken by the u,v,w anemometers is still being analyzed and, therefore, will not be presented in this report. When the analysis is complete, the results will contribute to dispersion modeling exercises using data collected during Phase I and anticipated data from Phase II.

Visibility Measurements

The integrating nephelometer draws an air sample, passes a light through the air sample and measures the scattering of the light. It is possible to relate the light scattering to visibility reduction by assuming that no light is absorbed by the particles present in the air. This assumption is expected to be quite good for low concentrations of particles of soils. Carbon particles obviously would be expected to absorb significantly, however, so that as the percentage of carbon present increases, the actual visibility degradation might be greater than indicated by the instrument. A major disadvantage of the nephelometer is the fact that it takes a local, small air sample. Obviously, if the atmosphere is homogeneous, then this small sample is representative. For looking at long distances, especially in mountainous topography, such a sample must be viewed as an indication of local conditions only.

Generally, visibility is reported in terms of visual range, defined as the longest theoretical distance that one can distinguish a target against a background. The theoretical limit to visibility is Raleigh scattering, namely scattering by the air molecules totally free from any suspended aerosol. Raleigh scattering suggests a visual range on the order of 390 km.

Table 2 and Figure 6 provide summaries of the nephelometer data taken in western Colorado (10 km from the mine site) over an 11 month period. Visual ranges vary from a maximum of 377 km to a minimum of 36 km. The interpretation

FIGURE 4

QUANTITY OF COAL IN DUST FALL SAMPLE
7/30/79 - 8/3/79

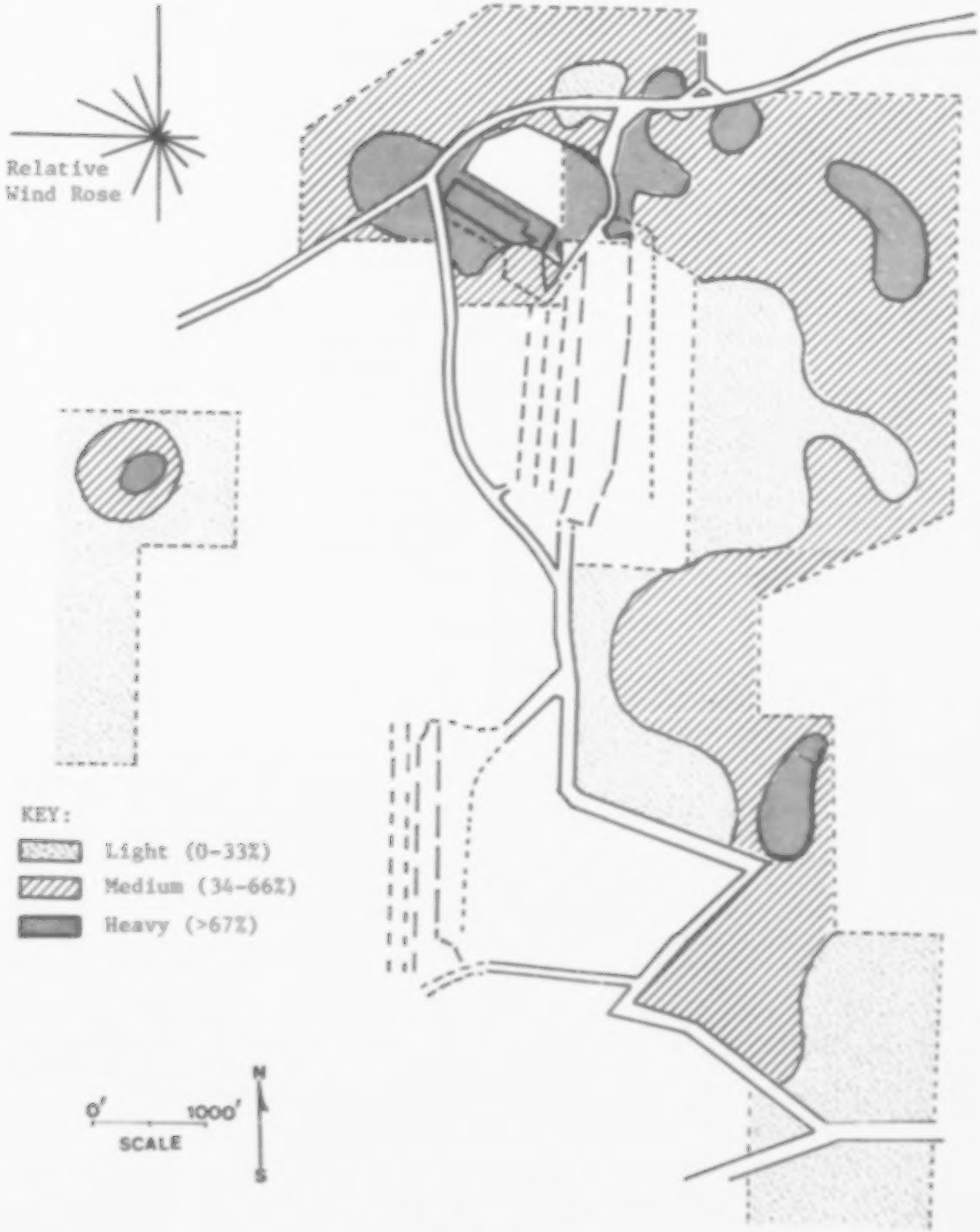

Relative
Wind Rose
KEY:
Light (0-33%)
Medium (34-66%)
Heavy (>67%)
0'
1000'
SCALE
N
S

FIGURE 5

TEMPERATURE, RELATIVE HUMIDITY AND WIND VELOCITY TETHERSONDE SOUNDINGS

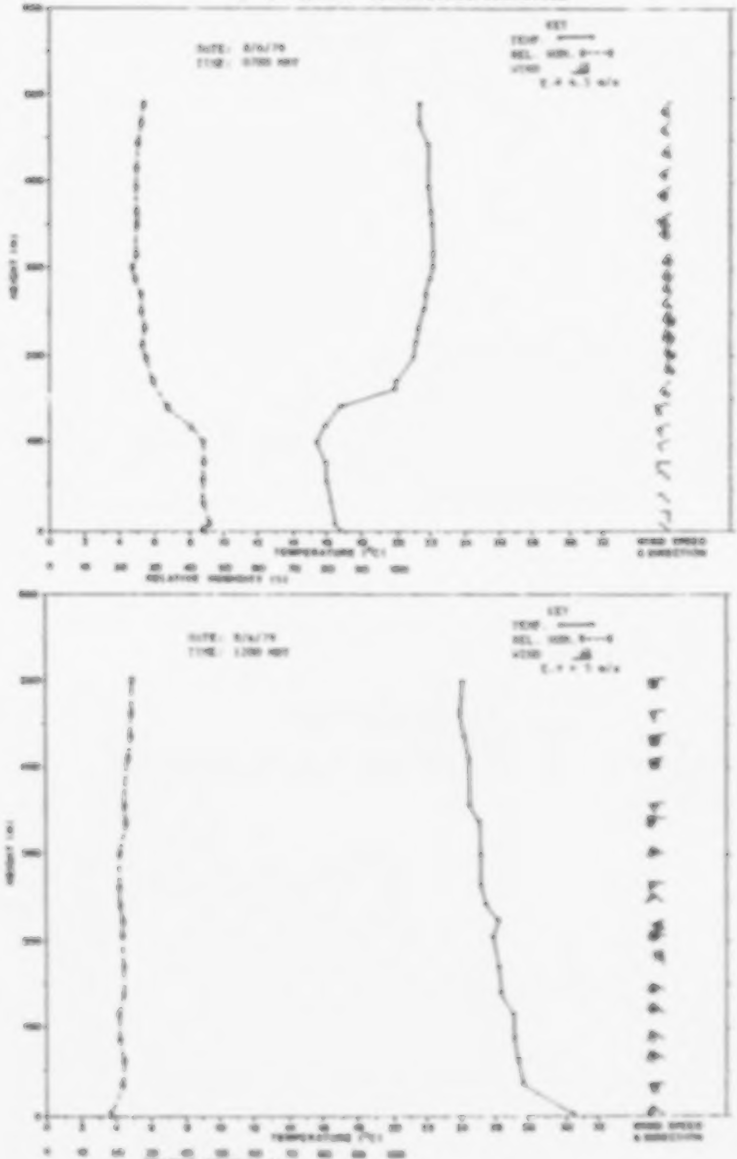


TABLE 2

NEPHELOMETER

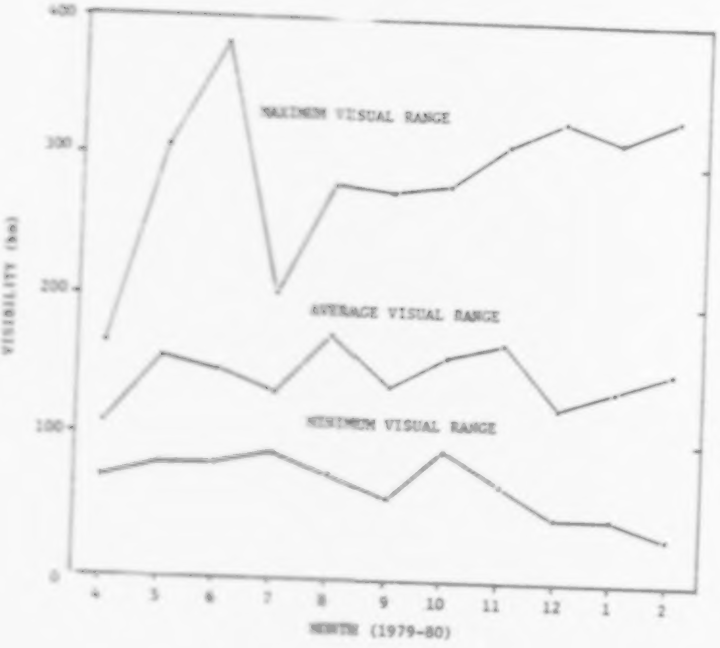
Visual Range

(km)

Month/Year	Max	Min	Std. Dev.	Mean
4/79	166	69	29	107
5/79	307	81	45	156
6/79	377	81	49	151
7/79	207	86	27	134
8/79	280	74	43	175
9/79	278	58	65	141
10/79	279	93	40	160
11/79	311	70	56	169
12/79	329	46	59	124
1/80	310	45	58	137
2/80	327	36	71	153
Averages	289	67	-	146

FIGURE 6

NEPHELOMETER RESULTS



of these data, however, is not straight forward. Visibility decreases and increases from day to day for a great many reasons. A longer record will be needed in order to reach valid conclusions about any effects of mining activity on visibility. It is interesting to note one comparison with a telephotometer observation; Malm, et al. (1979) presented results from a number of locations. One location, Dinosaur National Monument, in northwestern Colorado could be considered to be in a visual environment similar to our study. The average visual range they measured for summer 1978 was 195 km and for spring 1979 was 169 km. The mean value we measured for spring 1979 was approximately 139 km, while summer 1979 was 150 km. The comparison should not be inferred to indicate anything other than the nephelometer at our site is indicating visual ranges the same order of magnitude as at Dinosaur.

Contrast telephotometer data taken over the same 11 month period are still being reduced, and are not presented in this report.

CONCLUSIONS

During the summer of 1979, Phase I of a two phase study was conducted to evaluate the sources, physical and chemical characteristics, and transport of particulate emissions from a surface mine in the semi-arid west. The study emphasized analysis of particulates near the emission sources within a working coal mine. A variety of air quality and meteorological instrumentation was utilized to collect data during two sampling periods. Results highlight the temporal and spatial variability of emission sources relative to meteorological conditions, type of equipment used, and type and scheduling of mining activities. Though this source variability complicates measurement and analysis of emissions, valuable information pertaining to the particulates that mining contributes to air quality can be investigated. Phase I field programs were conducted during the dry summer months under conditions where maximum fugitive emissions would be expected. Particulate measurements taken during the winter or wet spring would yield different results.

The uniqueness of a surface mining site (topography, soils-spoils, local meteorology, depth of coal seam, surrounding land use, and other factors) coupled with the engineering decisions employed to extract, transport and store the mineral resource, emphasize the difficulty in translating information gathered at one mine to other mines.

Phase II of this study will be conducted during the summer of 1980. Phase II will emphasize the measurement of particulates at increased upwind and downwind distances. Results from both phases will be integrated to thoroughly address the objectives and goals of the research effort. Increasing land disturbances and increasing numbers of industrial sources in the west will increase the level of particulates in the atmosphere. What, if any, contribution surface mining will have on air quality and visibility is a particularly difficult question to answer, but one that should be pursued. Land managers must have information available to assist them in making environmentally sound decisions relative to the utilization of the nation's valuable resources in the semi-arid west.

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FUGITIVE EMISSIONS CONCERNS FOR COAL STORAGE AND HANDLING AT UTILITY OPERATING STATIONS

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Measurement and Control
May 28-30, 1980
Monteleone Hotel, New Orleans, Louisiana

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ABSTRACT

This paper discusses the potential impact on utility operations of fugitive particulate matter emissions from coal storage and handling. It is based primarily on a study completed by TRC for a large utility.

Utilities seeking to convert to coal firing or preparing to reactivate older coal systems will be faced with a number of concerns, including:

- What are the probable magnitudes of the fugitive emission?
- What type of fugitive emission control systems are available?
- What modeling techniques are available to assess the impact on air quality of fugitive emissions?
- What are the design characteristics of various types of coal handling components with respect to fugitive emission potential?
- What are the ramifications of fugitive emissions control with respect to BACT and LAER under the Clean Air Act?

In developing a fugitive emissions inventory and applying the findings to decisions regarding the feasibility of resuming coal firing, the utility and TRC found it necessary to formulate answers to the foregoing questions. The paper presents discussions related to each of these concerns, with the objective of providing a general guideline to the utility managers who must address these problems.

1.0 FUGITIVE EMISSIONS CONCERNS FOR COAL STORAGE AND HANDLING AT UTILITY GENERATING STATIONS

1.1 Introduction

The U.S. dependence on imported oil for utility power generation has continued to grow in the years since the 1973 oil embargo. Coupled with the Three Mile Island incident, this has given major impetus to the early assessment of opportunities for increased power generation by coal combustion. However, the increased utilization of coal has been cited as carrying an inherently greater air pollution potential than any other form of power generation. Among the potentially serious sources of air pollution from coal-fired power generation are fugitive emissions of particulate matter from coal storage and handling operations.

Utilities considering the switch to coal firing, or preparing to reactivate older coal systems, must be concerned with fugitive emissions from the delivery, loading/unloading, transport, storage and processing of coal. TRC has recently completed a study for a large utility which inventoried the fugitive emissions for a projected resumption of coal firing at selected generating stations. The major technical problem of the study was the meaningful quantification of the particulate matter fugitive emissions. Direct measurement of such emissions from individual sources is an exceedingly expensive process, with costs at least an order of magnitude greater and accuracy inherently lower than for conventional stack testing. Thus estimation of emissions by emission inventory/emissions factor techniques, although not nearly as well defined as for point source emissions, was selected. Similarly, the nature and performance of emissions control systems for coal operations fugitive emissions are not well established, and there is a serious lack of information on the degree to which fugitive emissions can be designed out of the available options in coal handling equipment.

Given this framework, a stringent schedule, and a limited budget, TRC sought to predict fugitive emissions quantities and control performance from information available in the open literature, and by the application of judicious engineering judgment. The calculated emissions were then to be used as input to a mathematical model which would predict the air quality impact of the emissions and allow individual source contributions to be isolated.

This paper reviews the findings of the study, with the objective of providing general guidelines to the utility managers who must address coal fugitive emissions problems. The discussion will be directed to the following questions:

- What are the probable magnitudes of the particulate matter fugitive emissions and how are they distributed among the coal system components?

- What types of fugitive emissions control systems are available for each coal system component, and what are their probable efficiencies? What is considered BACT?

- What are the design characteristics of various types of coal handling components with respect to fugitive emission potential? To what degree are these quantifiable?

- What are the ramifications of coal handling fugitive emissons control, with respect to BACT and LAER under the Clean Air Act?

- What modeling techniques are available to assess the impact on air quality of particulate fugitive emissions, and how well can they isolate the contributions of the major sources within the coal system complex?

2.0 EMISSION FACTORS

The answers to the first three questions raised in the Introduction were sought through a comprehensive literature survey. The objective of this survey was to determine the range of fugitive particulate matter emission factors applicable to coal storage and handling, and the range of control efficiencies to be expected from appropriate control techniques. The literature review encompassed the recent studies by PEDCO and Midwest Research Institute, and the information generated by TRC's ongoing studies for EPA. In all cases, the literature sources were critically reviewed in terms of the means used to arrive at the emissions factors given, the type of operation for which they were developed, and their applicability to existing or visualized coal handling operations. A literature pool of 12 references resulted from this review, and formed the basis for the emission factors used in the study. These are given in the reference section of this paper.

The fugitive emission factors from the literature were classified as follows:

- coal delivery: rail car
  barge
- coal transfer: belt conveyors
  transfer operations
- coal storage: active storage
  inactive storage

Table I summarizes the emission factors which were selected from the literature for these classifications, and also shows further refinement of the factors, based on a critical assessment of currently installed and expected equipment at the generating stations in question. It is this step which requires the application of engineering judgment based on experience. The "refined" factors which appear in Table I therefore should be viewed as somewhat site-specific, and would probably differ for other installations.

In applying the refined factors, the use of the ranges is recommended, as opposed to so-called "best estimate" single values. The carrying of a range of calculated emissions throughout the process will serve to remind all concerned that the emission values being developed incorporate a considerable degree of uncertainty.

The form of the emission factors for storage and transfer operations raises questions as to their physical validity. For example, the literature did not provide a specific factor which reflected the influence of the length of a conveyor, which seems the logical way of assessing the emissions from this type of source (emissions per unit length). Thus the factors expressed on the basis of through-put of coal conveyed or transferred were used, despite their obvious shortcoming in excluding the length factor.

In the case of inactive storage, one would expect the emissions to be related to windspeed and frequency of rainfall. While there are empirical emission factor equations available which take these into account, most of the literature emission factors were given in terms of the quantity placed in storage (annual basis) and this convention was adopted despite the lack of accounting for other physical aspects of the situation.

In the case of the active stockpile, it is recognized that there are several specific emission-generating processes which take place; i.e. load-in, load-out, vehicular traffic around the storage pile, and wind pickup. Each process would be expected to have a specific emission factor. Many literature sources did, in fact, attempt to distinguish among these individual sources. The typical active storage operations are usually located relatively close together, and the processes do not occur occur simultaneously. Thus, a single emission factor was judged to be most appropriate. Fortunately, such a factor was available in the literature (Ref. 4) and was adopted for use in the study. The single value given (0.22 kg/metric ton) was assigned a range of 0.11 to 0.33, in recognition of the likelihood that, even if obtained in a well-run experiment, such a factor would be determined from data scatter exhibiting at least a ±50% range.

TABLE 1
SUMMARY OF UNCONTROLLED PARTICULATE MATTER FUGITIVE EMISSION FACTORS FOR COAL OPERATIONS AT UTILITY POWER PLANTS

Operations	Uncontrolled Emission Factor From Literature (kg/metric ton)	Refined Uncontrolled Emission Factor[1]	Reliability Ratings Found In Literature[2]
Coal Delivery:			
(1) Railcar	0.0001 - 0.2	0.025 - 0.2	B, C, D, E
(2) Barge	0.0001 - 0.2	0.01 - 0.1	C, E
Coal Storage:			
(1) Inactive Storage Piles	0.055[3]	0.03 - 0.08[4]	B
(2) Active Storage Piles	0.22[3]	0.11 - 0.33[4]	B
Coal Transfer:			
(1) Belt Conveyor	0.02 - 0.5	0.02 - 0.2	D, E
(2) Transfer Operations	0.075[5]	0.04 - 0.12[4]	N/A (E)[5]

3.0 EFFICIENCY OF CONTROLS

Information on availability and expected effectiveness of control systems for fugitive particulate emissions from coal operations was also gleaned from the literature. Again, application of engineering judgment led to the refining of the literature values to provide efficiencies which could be applied to the existing or anticipated installations under study. In the case of control efficiency, a single "refined" value was selected from the literature range. This specificity could seem unwarranted in view of prior discussion regarding the uncertainties of the whole emission calculation process. However, it was felt that "engineering judgment" is more consistent with a single efficiency value than a single-valued emission factor, and there seemed to be insufficient justification for further widening of the range of uncertainty by assigning a control efficiency range.

Table 2 summarizes the control efficiency values which were selected from the literature for the same coal operation classifications used in Table 1. The "refined" efficiency value is given along with the nature of the control technique which could be expected to provide that efficiency. The "remarks" column gives information as to the probable maximum control efficiency available if cost of control were not a factor. The "refined" efficiency value and associated control type could also be viewed as providing a "practical" level of control, at least as far as the operations which were the subject of the TRC study are concerned.

TABLE 2
SUMMARY OF CONTROL EFFICIENCIES FOR PARTICULATE MATTER FUGITIVE EMISSIONS FOR COAL OPERATIONS AT UTILITY POWER PLANTS

Operations	Control Efficiency Range From Literature	Refined Control Efficiency & Nature of Control	Remarks
Coal Delivery			
(1) Rail Car Unloading	90 - 99%	95% Ventilation of Enclosure to Baghouse	Complete Enclosure is Difficult With Unit Train Dumping Systems
(2) Barge			
(a) Unloading	70 - 90%	75% Unventilated Enclosure	
(b) Loading	50 - 90%	75% Telescopic Unloading Chute & Local Ventilation and Control	95% Feasible With Enclosure, Ventilation and Control, But Very High CFM
Coal Storage			
(1) Inactive Storage Piles	50 - 100%	50% Wetting and Chemical Stabilization	Virtually 100% if Fully Enclosed, But Not Usually Practical With 30, 60 or 90 Day Piles at Large Stations
2) Active Storage Piles	50 - 75%	75% Wetting & Chemical Stabilization Plus Local Ventilation and Baghouse	95% Feasible With Enclosure, Ventilation and Control, But Very High CFM
Coal Transfer			
(1) Belt Conveyor	95 - 99%	97% Conveyors Enclosed But Not Ventilated	99% If Conveyors Properly Enclosed & Ventilated to Control, But Very Sensitive to Leaks
(2) Transfer Operations	90 - 99%	98% Enclosed; Ventilated to Baghouse	Usually Enclosed to Start With

4.0 BEST AVAILABLE CONTROL TECHNOLOGY (BACT)

The requirements of the Clean Air Act Amendments of 1977 specify that new or modified sources in certain process categories, whose emissions could impact criteria pollutant air quality attainment areas, be required to install Best Available Control Technology, (BACT). BACT is determined on a case by case review basis, and only limited information, as shown on Table 3, is presently available on BACT for coal handling fugitive emissions. Table 3 shows that the required efficiency of BACT for coal handling and storage and similar operations could conceivably range from an unspecified "do the best you can" to complete enclosure with ventilation and baghouse control and 99.7% efficiency. The control efficiencies obtained from the literature and "refined" by TRC as shown on Table 2, are generally consistent with the BACT values given. Only the 90% efficiency of the raw coal storage pile dedusting agent for the Region V Coal Cleaning Plant seems inconsistent. Lacking more detailed information, an efficiency of 50% would be more in keeping with the information encountered in the TRC study. At best, we could visualize no more than 75% control if the dedusting agent were used in conjunction with carefully placed windscreens/barriers at the active sites of the storage piles. 90% control is expected to require a substantial degree of enclosure or covering of the pile, in conjunction with a dedusting agent.

TABLE 3
SUMMARY OF BEST AVAILABLE CONTROL TECHNOLOGY DETERMINATIONS¹ FOR PARTICULATE MATTER FUGITIVE EMISSIONS FOR COAL HANDLING AND STORAGE OPERATION

Process/Operation	EPA Region	BACT Strategy Description	Control Efficiency Specified	Remarks
Petrochemical	VI			
Coal Crusher		Baghouse Filters	99.7%	Controlled efficiency to include capture ventilation system (Totally Enclosed)
Coal Bunker		Baghouse Filters	99.7%	
Coal Handling		Shrouded Conveyors; Water Spray at Crusher; Dust Collection at Transfer Points	Not Given	
Coal Cleaning Plant	V			
Truck Dump		Capture & Fabric Filter Fabric Filter	80% 99%	
Rotary Breaker		Capture Plus Fabric Filter	80%	
Raw Coal Transfer Belts		Dedusting Agent	90%	
Raw Coal Sampling Building		Dust Collector	90%	
Preparation Plant Duct Belt		Dust Collector	99%	
Coal Cleaning Plant	IV			
Truck Dump		Enclosed Wet Suppression	90%	
Screen's Transfer Points		Enclosed Wet Suppression	90%	
Crusher		Enclosed Wet Suppression	90%	Assumed that no ventilation used in conjunction with these
Surge Bins		Not Given	90%	
Stock Piles		Enclosed Wet Suppression	90%	
Loading		Wet Suppression	90%	
Electrical Generating Station	IX			
Coal Handling		Spray Application And Dust Collectors	Not Given	Detailed Control Stragegy Info is Given in Permit
Coal Classification Plant	IX			
Aggregate Coal Storage		Water Sprays	Not Given	
Loading Areas				
Oil Shale Project	VIII			
Roads, Parking Areas, Drill Pads and Shale Deposit Areas		Water Sprays & Chemical Controls	"To Greatest Extent Possible"	

NOTES:

1. SOURCE: "Compilation of BACT/LAER Determinations": EPA

5.0 MAGNITUDE OF EMISSIONS

The significance of particulate fugitive emissions may best be judged by the application of the foregoing emission factors and control efficiencies to a typical coal handling and storage situation. The calculations are summarized on Table 4. These are abstracted from the TRC study, with appropriate simplification of the system and modification of throughput values.

The "typical" plant is assumed to burn 5000 metric tons of coal per 24 hours, which provides approximately 5500 X 106 BTU/hr heat input and is about equivalent to a 600 MW plant.

The total fugitive particulate emissions estimated for this typical plant are significant, even after application of controls which could certainly be considered BACT. At the high end of the range of annual emissions, over 100 TPY would be emitted. The active stockpile is seen to be the largest contributor (40% of the total), which is not suprising, since this operation involves actively disturbing and working the coal in the open. Significant additional control could only be achieved by completely enclosing the operation, and by ventilating to a baghouse or other control device. The maximum contribution of the conveyors (30 metric tons, or 21%) seems intuitively too high. Although the selected upper value for the uncontrolled emission factor of 0.2 kg/metric ton is well supported by the literature, its application to each conveyor section may be suspect. The available information did not clearly state whether the conveyor uncontrolled factors should be applied to the entire conveyor system, or to each section. In the TRC study, we adopted the latter, more conservative approach, and this is reflected in Table 4.

TABLE 4
CALCULATION OF PARTICULATE FUGITIVE EMISSIONS FROM COAL HANDLING AND STORAGE OPERATIONS FOR A TYPICAL COAL FIRED GENERATING PLANT

Emission Source And A Throughput	Uncontrolled Emission Factor	Control Type And Efficiency	Emissions Estimate	
			24 Hr	Annual
Unit Train Rotary Car Dumper 5,000 Metric Tons/24 Hr 1 x 10^6 Metric Tons/Yr	0.025 - 0.20	Enclosure; Ventilation; Baghouse: 95%	7-50 kg	1.3 metric -10 tons
Conveyors 5,000 Metric Tons/24 Hr 1 x 10^6 Metric Tons/Yr	0.020 - 0.20 Per Conveyor Section Assume 5 Sections	Enclosed; Well Sealed; 97%	15 - 150 kg	3 - 30 metric tons
Transfers 5,000 Metric Tons/24 Hr 1 x 10^6 Metric Tons/Yr	0.04 - 0.12 Per Transfer Point Assume 4 Transfers	Enclosed; Ventilation; Baghouse; 98%	16 - 48 kg	3.2 - 9.6 metric tons
Active Stockpile 2,000 Metric Tons/24 Hr 0.5 x 10^6 Metric Tons/Yr	0.11 - 0.33	Wetting; Chemical Stabilization; Local Ventilation to Baghouse; 75%	55 - 165 kg	13.8 - 41.3 metric tons
Inactive Stockpile 90 Day Storage (450,000 Metric tons in storage)	0.03 - 0.08	Wetting; Chemical Stabilization; 50%	19 - 50 kg (annual emissions divided by 365)	6.8 - 18 metric tons
TOTAL EMISSIONS			112 - 463 kg (246-1019 lb)	28.1-108.9 metric tons (30.9-120 short tons)

6.0 COAL HANDLING COMPONENTS

The design of the coal handling system components can significantly influence the magnitude of uncontrolled fugitive emissions. That is, the degree to which the design minimizes the mechanical agitation of the coal, will be reflected in reduced emissions. The operations which are most involved with such mechanical manipulation of the coal, and which contribute significantly to the total fugitive emissions are:

- coal unloading
    - from trains
    - from barges

- coal loading
    - to barges
    - to trains

- active stockpiles
    - coal delivery to the piles
    - coal reclamation from the piles

The emission factor literature rarely distinguishes among various available equipment arrays for accomplishing these functions. Ideally, one would assume that the uncontrolled emission factor would range from the high extreme to the low extreme as the equipment's inherent capability to disturb the coal is decreased. Unfortunately, there is no specific information to support this speculation and one can only surmise in a general way as to which method (e.g., of delivering coal to a storage pile), generates the least fugitive emissions.

Figure 1 illustrates this, schematically showing two ways of accomplishing several of the functions in the order of (probably) decreasing emissions.

For barge unloading, the continuous unloader, which is a shrouded and articulated bucket conveyor, would be expected to generate substantially less fugitive emissions than the grapple bucket unloading method. The continuous unloader also offers the opportunity to apply reasonably effective local ventilation.

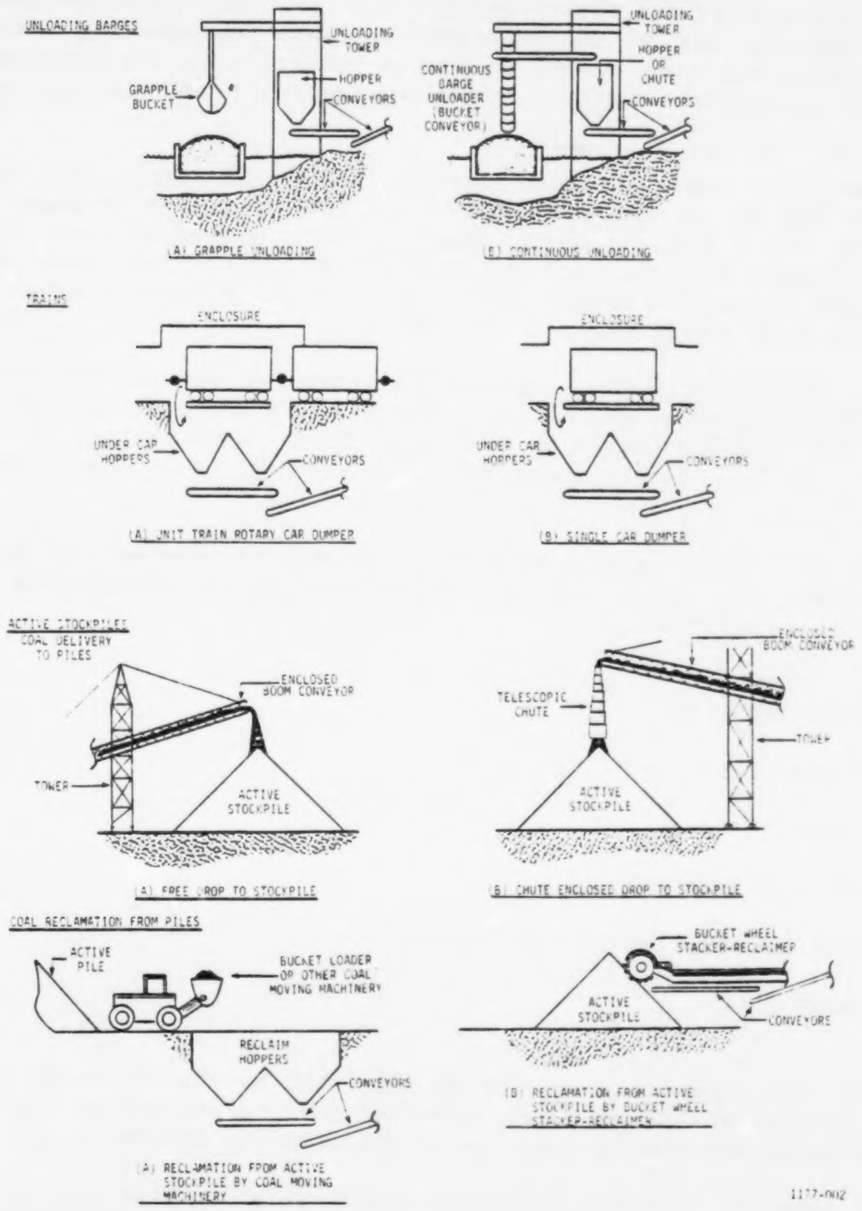
In the case of trains, it is not apparent that a rotary car dumper designed to invert coal rail cars while they remain coupled, could generate more fugitive emissions than a single car dumper, except to the extent that a single car is more readily enclosed. The unit train system would operate more rapidly and thereby generate more emissions in a given time period, given equal control effectiveness. In either case, the train unloading system can be expected to be enclosed, ventilated and controlled, so in this case, the degree to which one version can generate more fugitive emissions than the other may be a moot point.

Active stockpile coal delivery is shown in two versions. One entails a free drop to the stockpile, while the second incorporates a telescoping chute to essentially enclose the coal stream during the drop. It is apparent that the latter method will generate less fugitive emissions.

Coal pile reclamation is shown in two systems which could be construed as "manual" vs. "automatic". The use of earth moving equipment around the pile, such as bucketloaders, bulldozers or graders which carry or push the coal to underground hopper/conveyor systems, can be expected to generate substantially greater fugitive emissions than an articulated bucket wheel stacker/reclaimer with associated conveyors. The latter would be shrouded and can be subjected to local ventilation and control.

In summary, the design features of coal handling component and systems can be a positive factor in minimizing fugitive emissions from the operation. Quantification of emission characteristics for various designs is beyond the present state of knowledge, and only educated estimates can be used to recognize that one component array may generate less emissions than another.

FIGURE 1: THE EFFECT OF COAL HANDLING COMPONENTS ON FUGITIVE EMISSIONS


UNLOADING BARGES
GRAPPLE BUCKET
UNLOADING TOWER
HOPPER
CONVEYORS
(A) GRAPPLE UNLOADING
CONTINUOUS BARGE UNLOADER (BUCKET CONVEYOR)
UNLOADING TOWER
HOPPER OR CHUTE
CONVEYORS
(B) CONTINUOUS UNLOADING
TRAINS
ENCLOSURE
UNDER CAR HOPPERS
CONVEYORS
(A) UNIT TRAIN ROTARY CAR DUMPER
ENCLOSURE
UNDER CAR HOPPERS
CONVEYORS
(B) SINGLE CAR DUMPER
ACTIVE STOCKPILES
COAL DELIVERY TO PILES
ENCLOSED BOOM CONVEYOR
TOWER
ACTIVE STOCKPILE
(A) FREE DROP TO STOCKPILE
ENCLOSED BOOM CONVEYOR
TELESCOPIC CHUTE
TOWER
ACTIVE STOCKPILE
(B) CHUTE ENCLOSED DROP TO STOCKPILE
COAL RECLAMATION FROM PILES
ACTIVE PILE
BUCKET LOADER OR OTHER COAL MOVING MACHINERY
RECLAIM HOPPERS
CONVEYORS
(A) RECLAMATION FROM ACTIVE STOCKPILE BY COAL MOVING MACHINERY
BUCKET WHEEL STACKER-RECLAIMER
ACTIVE STOCKPILE
CONVEYORS
(B) RECLAMATION FROM ACTIVE STOCKPILE BY BUCKET WHEEL STACKER-RECLAIMER
1177-002

7.0 MODELING OF FUGITIVE PARTICULATE MATTER EMISSIONS

The foregoing sections have described concerns and methodology related to the quantificaton of fugitive particulate matter emissions, and the means available for their control. Determination of the impact of these emissions on ambient air quality and their specific contribution to ambient concentrations requires the use of sophisticated mathematical modeling techniques. These techniques also are needed to assess tradeoffs in the application of controls to individual fugitive emissions sources, and to nearby point sources.

The immediate need for such refined analytical techniques has been acknowledged and met by EPA with the recent development of advanced dispersion models. The Industrial Source Complex (ISC) Dispersion Model developed by the H.E. Cramer Co. Inc., and the CDMDEP Model, a modified version of the Climatological Dispersion Model (CDM), developed by TRC Environmenal Consultants are two such models prepared for the EPA.

The ISC Dispersion Model combines and enhances various EPA dispersion model algorithms into a set of two computer programs that can be used to assess the air quality impact of emissions from a wide variety of sources, associated with an industrial source complex such as a Power Generating Station.

The ISC and CDMDEP models have been designed to account for mechanisms which influence the dispersion and quantification of particulate plumes. These mechanisms include:

- dry deposition
- gravitational settling
- washout
- building wake effects
- vertical wind profile variations
- plume rise

Stack, Area and Volume sources can be simulated by the ISC Model programs. Long-term concentrations of total suspended particulate matter due to emissions from point and area sources can be estimated by CDMDEP.

Short term or long-term source-receptor relationships can be derived using the ISC Dispersion Model. The ISC Short Term Model (ISCST) is designed to calculate concentrations or deposition values for time periods of 1, 2, 3, 4, 6, 8, 12 and 24 hours. The ISC Long Term Model (ISCLT) uses STAR Meteorological Summaries to calculate seasonal and/or annual ground level concentrations or deposition values.

The input data required to run either ISC or CDMDEP consists of four categories:

- Meteorological Data
- Source Data
- Receptor Data
- Program Control Parameters

The details of the input data are given in references 13 & 14. The output from these mathematical models provides a quantitative estimate of the spatial distribution of air quality, averaged over the time period considered. Contributions from major sources within the industrial complex can be identified and appropriate controls prescribed. It should be noted that these advanced, complicated models are intended to be used by Air Quality Engineers and/or Meteorologists familiar with effluent dispersion characteristics and computer techniques. The models, with proper fundamental knowledge, can be applied to other types of studies such as:

- Stack design
- PSD analyses
- Source Permit Applications
- Monitoring Network Design
- Regulatory Variance Evaluation
- Control Strategy Evaluations
- Fuel Conversion Studies
- New Source Reviews
- Analyses of Emission Offsets

8.0 CONCLUSIONS

This paper has reviewed a methodology for estimating the quantities and degree of control for fugitive particulate matter emissions from coal handling operations. Available information in the form of emission factors and estimates of control efficiencies was found to be relatively sparse and to vary widely. Information on BACT controls is also limited at present. Considerable judgment must be incorporated in the application of information. The estimation of well-controlled fugitive particulate emissions from a typical coal-fired plant results in significant residual emissions, of which a large proportion is due to actively working the stored coal in the open. More information on the relationship between coal handling equipment design characteristics and fugitive emissions is needed.

Mathematical Models are available which will discriminate among various fugitive emission sources and elevated point sources to isolate their individual impacts on ambient concentrations of suspended particulate matter. Application of these models completes the assessment of fugitive emissions and leads to the formulation of cost-effective control strategies.

There is at present enough information to only generally guide those managers who must address coal fugitive emission problems at utility stations. Each site will have its specific problems and constraints. The manager is urged to approach the problems utilizing a broad team of experts. Air pollution control engineers, power generation specialists, diffusion meteorologists, coal systems designers, environmental consultants, and environmental attorneys can all provide important inputs to the problem solutions. The success and cost effectiveness of the solutions will depend on how well the efforts of the team are orchestrated.

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Design, Performance Testing and Field Operation of an Isokinetic Electrostatic Particle Sampler

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Abstract

An isokinetic electrostatic particle sampler is described. Its performance is investigated both in laboratory and field operation.

The sample flow is generated from the inertia of the surrounding air flow. The particles in the sample flow are deposited inside a cylindrical collector electrode, which is weighed before and after the sampling period. Afterwards, the sample can be further analyzed for its chemical composition or physical properties. The particle flux is obtained by dividing the inlet nozzle area with the sample mass and the sampling time.

The collection efficiency has been studied under various controlled conditions. It is seldom lower than 90%, but often above 97%. Wind tunnel tests have been performed to study the deviation from isokinetic sampling. The maximum deviation found was 8% in the 0.5 - 26 m/s range.

The sampler may be used for measurement of fugitive dust emission, its operation being wind-directed and the sampling being merely in a 45-degree-sector or similar. Evaluation procedures for fugitive emissions from ideal point sources, line sources and surface sources are presented.

Experiences from field measurements are reported. Measurements have been performed in roof ventilators and around an open stock pile area of a smelter industry. In the latter case 13 samplers placed in 4 masts were operated during one year.

Design, Performance Testing and Field Operation of an Isokinetic Electrostatic Particle Sampler.

Bengt Steen, Swedish Water and Air Pollution Research Institute

General

Measurement of fugitive dust emissions are more difficult to perform than other dust emission measurements. Several factors complicate the measurement:

- particle sizes are often large
- changes in both flow velocity and direction may occur
- part of the emission may be occational, for instance in connection with high wind speed. This requires long sampling periods to obtain necessary statistics
- the extension of areas with high fugitive emission source strength is often vaguely known
- areas with fugitive emission are often large, which calls for many measurement points

Taking these complicating factors into account emphasis should be laid upon two qualities of a good measurement method for fugitive dust emissions,

- isokinetic sampling
- low cost

Five years ago we developed a sampler at our institute to meet these quality demands (1).

Design

After some field experience the sampler was modified. The new design is shown in Figures 1 and 2.
The sampler consists basically of a nozzle, a cylindrical collecting electrode, an emission electrode, a flow regulator, a shaft and a high voltage generator.

During sampling, the axis of the cylinder is parallel with the flow lines and the fluid is allowed to pass isokinetically through the nozzle by means of its own inertia. The particles are charged and collected on the inner cylinder wall by electrostatic forces. The cylinder is weighed before and after the sampling to determine the particle mass. The particles may also be analysed by chemical or physical means.

The particle flux is determined by dividing the sample mass with the nozzle area and sampling time.

The nozzle diameter is such that approximately 25 times reduction of the air velocity is obtained inside the sampler. The combined dimensions of the nozzle, the collecting electrode, the outlet holes and the venturi screen result in an isokinetic flow through the nozzle tip.

Performance testing

Measurements of the flow velocity in the nozzle and in the main gas stream showed little or no difference from isokinetic conditions, (table 1). The deviations are such that to some degree they compensate a decreasing sampling efficiency at high wind speed.

Flow velocity in main gas stream (m/s)	Flow velocity in nozzle tip of the sampler (m/s)	Note
0.5	0.5	measurements made by hot wire anemometer at room temperature
0.8	0.8	
2.3	2.3	
3.4	3.4	-"-
5.5	5.6	-"-
9.8	10.0	-"-
12.3	13.0	-"-
25.8	28.0	measurements made with static and dynamic pressure sensors at 260 °C.

Table 1 Results of flow velocity measurements in nozzle tip and in main gas stream

The collection efficiency of the sampler has been tested at various conditions. The influence of particle size, concentration, flow velocity, amount of collected material, particle material, and battery current has been studied (1).

The experimental set-up consisted either of: (a) the sampler, a filter, a dry gas meter and a pump; or (b) the sampler, a Royco 220 light scattering particle counter and a pump.

Table 2 shows the results obtained by using a Royco particle counter when determining the concentration of different particle size classes present in a room atmosphere before and after the sampler. The sampler was used without a nozzle and with a flow velocity of 1 m/s inside the collection electrode. The particle number concentrations were low, around 1000/l in the 0.3-0.4 μm range and 10-21/l in the 3.4-6.6 μm range.

Latex equivalent particle diameter (μm)	Sampling efficiency (%) Battery current (mA) 6	8	10	50	196
0.3-0.4	73.7	83.2	93.7	97.6	99.0
0.4-0.6	72.9	83.8	94.5	97.5	98.7
0.6-1.0	75.6	86.1	96.0	98.0	99.2
1.0-1.8	77.6	92.2	96.3	99.3	100
1.8-3.4	78.7	92.4	99.7	100	100
3.4-6.6	78.2	92.9	98.7	100	100
6.6-13	88.3	(80.0)	100	100	100

Table 2 Collection efficiency of sampler for different particle size classes at different battery currents

Table 3 Collection efficiency obtained from measurements of different types of particles.

Gas velocity at nozzle (m/s)	Nozzle dia. (mm)	Battery current (mA)	Type of particles	Amount of collected dust (mg)	Collection efficiency %
0.8	25	50	Redispersed soot from oil combustion	27.8	99
	25	50	Redispersed Na_2SO_4 from kraft pulp mill recovery furnace	8.7	98
0.8	25	50	Talc powder(mass mean aerodynamic diameter = 2.5 μm)	23.6	98
13.6	5	∿150	Emissions from electric arc steel furnace	389	97.5
0.8	25	50	Fe_2O_3	8.4	100
0.8	25	50	Particles in ambient air	5.3	91
0.8	25	50	Sulphate in particles in ambient air	0.201	87

The collection efficiency obtained by the filter method for various types of particles are shown in Table 3.

Comparative measurements between two samplers at different angles were made in a wind tunnel. The purpose was to study the influence of deviations between the direction of the main flow and sample flow on sample flow velocity.

Talc powder with a mass mean aerodynamic diameter of 2.5 µm was used at a wind velocity of 4 m/s. The result is shown in Figure 3.

Selection of sample points and data evaluation

Since the position and extension of a fugitive dust source generally are not known, many measuring points in an envelope surface around the source are needed to determine the total emission. By using an infinite amount of measuring points the location and evaluation are fairly easy to make. However, economic realities will put a limit to the number of measuring points. Presumptions or knowledge of the position and character of a certain source usually enable adequate measurements of the emission even by using a few samplers. A few such cases will be discussed below.

In all cases it has been assumed that the background is zero and that nothing of the emitted dust has been deposited between the emission point and the sampler.

Ideal point source

An ideal point source emits dust from one single well-defined point. Welding, loading- and unloading operations, minor storing places and open fires usually could be treated as ideal point sources. The size of the emission from an ideal point source is here supposed to be independent of the wind direction.

If one puts an imaginary cylinder with vertical axis and with the bottom surface concentrically with the source the particle flow through the envelope surface of the cylinder will be identically with the emission, provided that the cylinder wall is high enough and that the background is low. The particle flow through the envelope surface could be determined by using samplers located at different heights in the cylinder wall. If one mast with n samplers is used the emission will be the following

$$\frac{\sum^{n} m_i \cdot 8\ rh}{n \cdot d^2 \cdot f}$$

where
m_i = quantity of sample in the ith filter

n = number of samplers

r = radius of cylinder

h = height of cylinder

d = dia. of the sampler nozzle

f = relative frequency of wind direction in the sampling sector (Frequency of wind direction in the sector divided with the frequency in the sector if the wind was blowing with equal frequency from all directions)

If the background is high the particle flow coming in through the opposite side of the cylinder has to be measured and subtracted from the flow of the leeward side of the source.

Ideal line source

An ideal line source is here defined as a source which form looks like a line and which emission pro length unit is the same along the whole line. A road, a ditch or belt conveyor usually could be regarded as an ideal line source.

If we look at a length increment, dL at the line source as a point source, the following is valid

$$\frac{\sum m_{i,L}\, 8\cdot h\cdot r}{n\cdot d^2\cdot f} = dL\cdot a$$

where
a = the emission per length unit, and $m_{i,L}$ is that part of the sample which emanates from the length unit dL. If we integrate over the whole length of the line source (L_0) in the measuring sector we get:

$$\frac{\sum m_i\cdot 8\cdot h}{n\cdot d^2\cdot f} = a\cdot \int_{L=0}^{L_0} \frac{dL}{r} \qquad \ldots\ldots \quad (1)$$

This integral will here be solved for the case that the line source is a straight line which crosses both sides of the sampling sector (see fig. 4).

The equation of this straight line equation expressed in polar coordinates is:

$$r = \frac{p}{\cos\alpha - k\sin\alpha} \quad \text{where k and p are constants.}$$

Further $$L = \sqrt{(p - r\cdot\cos\alpha)^2 + r^2\sin^2\alpha} =$$

$$\sqrt{\left(p - \frac{p\cdot\cos\alpha}{\cos\alpha - k\cdot\sin\alpha}\right)^2 + \frac{p^2\cdot\sin^2\alpha}{(\cos\alpha - k\cdot\sin\alpha)^2}} =$$

$$p\sqrt{\frac{k^2\cdot\sin^2\alpha + \sin^2\alpha}{(\cos\alpha - k\cdot\sin\alpha)^2}} = \frac{p\cdot\sin\alpha}{\cos\alpha - \sin\alpha}\cdot\sqrt{k^2+1}$$

$$\frac{dL}{d\alpha} = p\sqrt{k^2+1}\cdot\frac{\sin\alpha\cdot(\sin\alpha + k\cdot\cos\alpha) + (\cos\alpha - k\cdot\sin\alpha)\cdot\cos\alpha}{(\cos\alpha - k\cdot\sin\alpha)^2}$$

$$= p\sqrt{k^2+1}\cdot\frac{1}{(\cos\alpha - k\cdot\sin\alpha)^2}$$

(1) then would be expressed as:

$$\frac{\sum m_i\cdot 8\cdot h}{n\cdot d^2\cdot f} = a\cdot\int_{\alpha=0}^{\alpha}\frac{p\cdot\sqrt{k^2+1}\cdot(\cos\alpha - k\cdot\sin\alpha)}{(\cos\alpha - k\cdot\sin\alpha)^2\cdot p}\,d\alpha =$$

$$= a\cdot\sqrt{k^2+1}\cdot\int_{\alpha=0}^{\alpha}\frac{1}{\cos\alpha - k\cdot\sin\alpha}\,d\alpha = a\cdot\ln\frac{(k+\sqrt{k^2+1}+tg\frac{\alpha}{2})\,(k\cdot\sqrt{k^2+1})}{(k-\sqrt{k^2+1}+tg\frac{\alpha}{2})(k+\sqrt{k^2+1})}$$

If a is released we get:

$$a = \frac{\sum m_i\cdot 8\cdot h}{n\cdot d^2\cdot f}\cdot\left(\ln\frac{(k+\sqrt{k^2+1}+tg\frac{\alpha}{2})\,(k-\sqrt{k^2+1})}{(k-\sqrt{k^2+1}+tg\frac{\alpha}{2})\,(k+\sqrt{k^2+1})}\right)^{-1}$$

Ideal surface source

Suppose that the extension of the surface source is limited by four lines which in polar coordinates are the equations $r = r_1$, $r = r_2$, $\alpha = 0$ and $\alpha = \alpha_1$ (α is given in radians). The measuring point is placed in origo. In the same way as earlier we will get the flow through a vertical slit in origo:

$$\frac{\sum m_i \quad 4}{n \cdot \pi \cdot d^2} = \int_0^{\alpha_1} \int_{r_1}^{r_2} \frac{r \cdot d_\alpha \cdot dr \cdot e \cdot f}{2 \cdot \pi \cdot r \cdot h}$$

e = the emission per surface unit.

Then we will get:

$$e = \frac{m_i \cdot 8 \cdot h}{f \cdot n \cdot d^2 \cdot \alpha_1 (r_2 - r_1)}$$

Field experience

The field experience with the sampler includes measurements in roof ventilators and a one-year measurement of the emission from a stock yard of a smelter industry in northern Sweden.

Roof ventilator measurement

An example of the location of samplers in a roof ventilator is shown in Figure 5.

Figure 6 shows a particle sample collected in a roof ventilator above an electric arc steel furnace. The particles were collected on an aluminum foil.

With a conventional technique including flow measurements and isokinetic sampling the same measurements would require several times the man power and equipment investments.

Stock yard measurement

Fugitive emissions from a stock yard were measured using 13 samplers during one year.

The samplers were mounted at light masts in the area as shown in Figure 7. They were directed towards different fugitive dust sources (Figure 8). The sampling took place with the wind blowing from these sources against the sampler and in a sector of ± 22.5 degrees from the main direction. One month samples were taken. The particles which had isokinetically passed through the sampler nozzle were collected on an aluminum foil, which weight was determined before and after the sampling period. The aluminum foil then was rinsed in distilled water and the suspension was analysed for Cu, Pb, Zn, As and mercury by means of ASV and atomic absorption spectrometry.

The fugitive emission was calculated in three ways. The results differ only slightly and is shown in Table 4. The losses of Cu and As is approximately 1 - 2 % of the handled amount of material.

Table 4 Total amount fugitive emission calculated in three ways.

Calculation criteria	Estimated total emission ton/year					Total Dust
	Cu	Pb	Zn	As	Hg	
Total emissions from single point sources.	15	7.5	140	1.7	0.23	2800
Total fugitive dust transportation from material handling yards, calculated from the transportation above the south bank (the poles A and B) which was multiplied with 3.7 (the area is presumed surrounded by a square. Through one of this sides the flow was measured)	6.9	$(25)^x$	110	1.4	0.055	2200
Mean dust flow in the area without consideration of the location of the samplers multiplied with the envelope surface of a cylinder with a radius of 400 m and a height of 25 m (will surround the area)	14	$(35)^x$	220	2.5	0.18	2200

x) the lead storage yard at the A-pole disrupt the result

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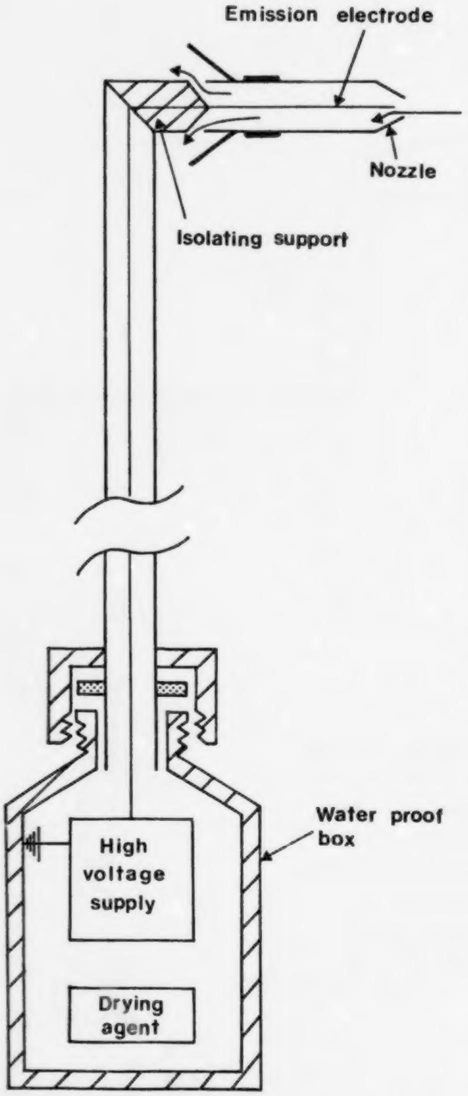
Emission electrode
Nozzle
Isolating support
Water proof box
High voltage supply
Drying agent

FIGURE 1 Isokinetic electrostatic particle sampler Principal sketch

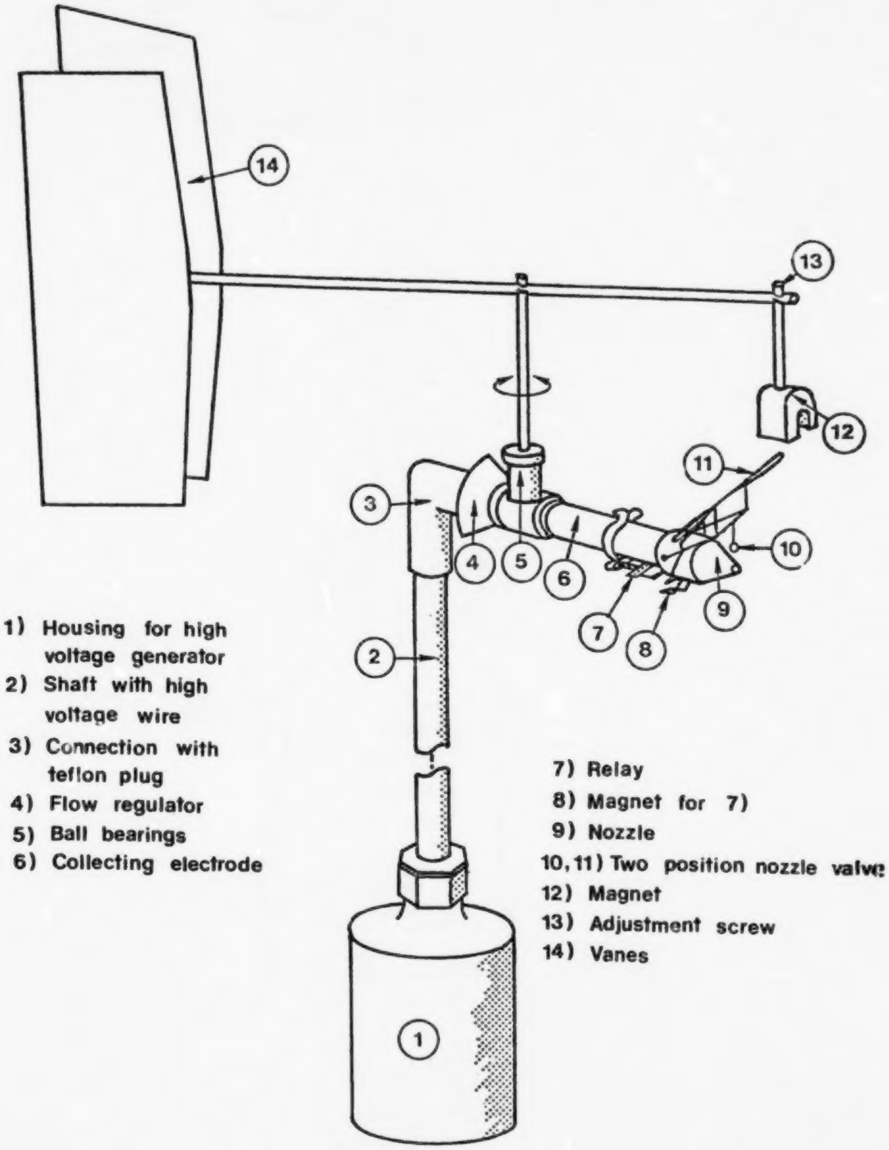
14
13
12
11
3
4
5
6
10
9
7
8
2
1
1) Housing for high voltage generator
2) Shaft with high voltage wire
3) Connection with teflon plug
4) Flow regulator
5) Ball bearings
6) Collecting electrode
7) Relay
8) Magnet for 7)
9) Nozzle
10,11) Two position nozzle valve
12) Magnet
13) Adjustment screw
14) Vanes

FIGURE 2 Wind-directed measurements

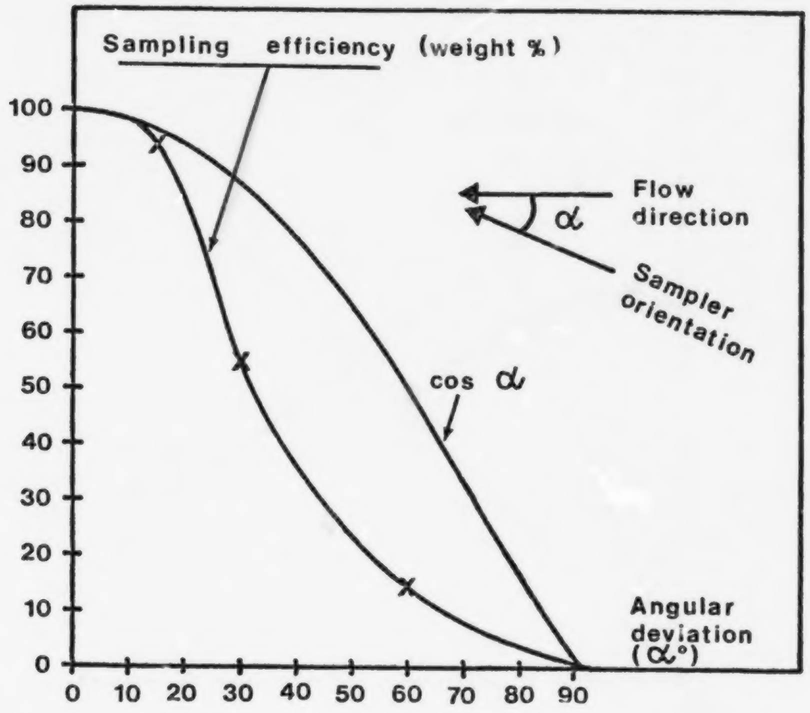

FIGURE 3 Percentage of main flux of talc dust obtained in a sampler oriented angular to the main flow direction at 4 m/s wind velocity

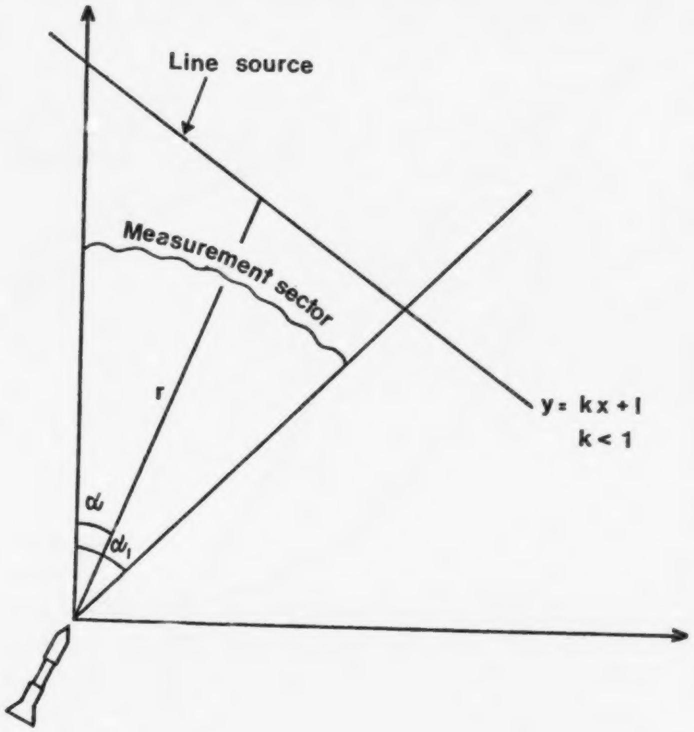
Line source
Measurement sector
r
y = kx + l
k < 1
α
α_1

FIGURE 4 Line source

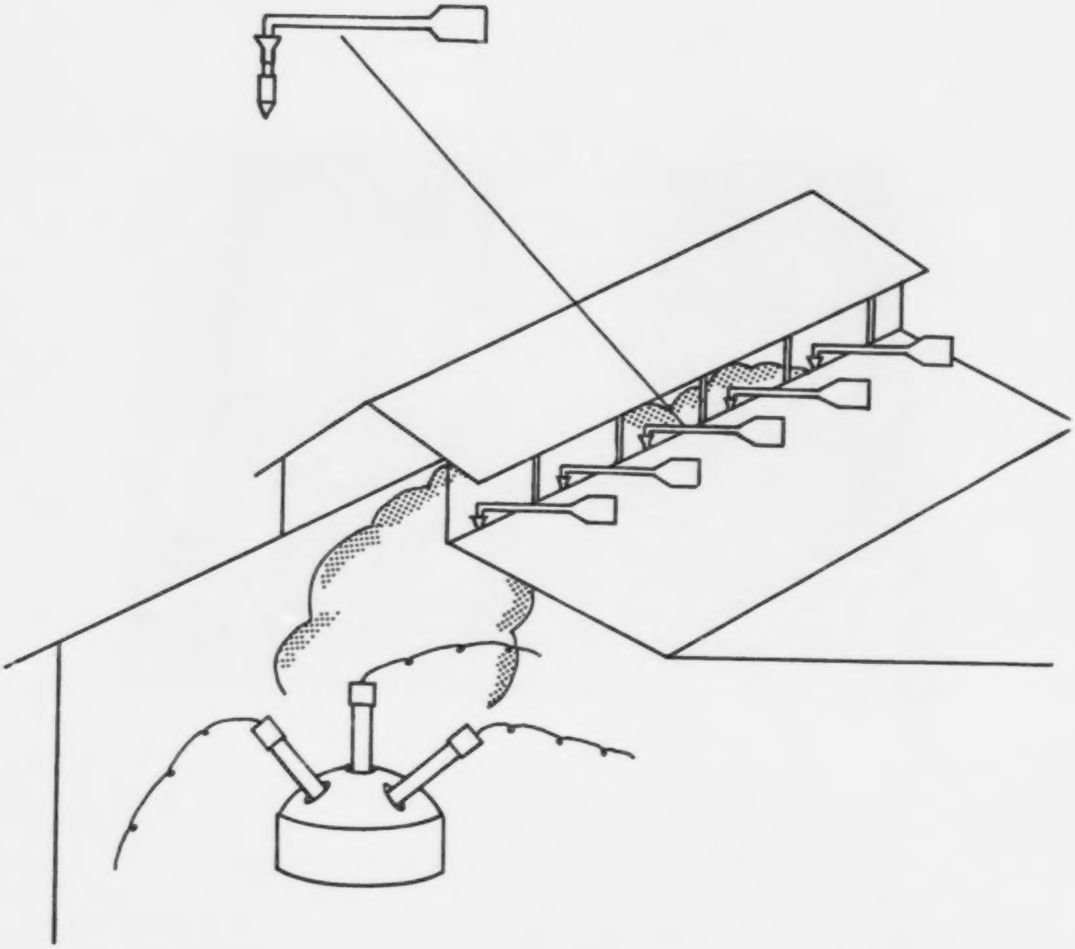

FIGURE 5 Measurement of fugitive emissions from roof ventilators. Location of samplers.

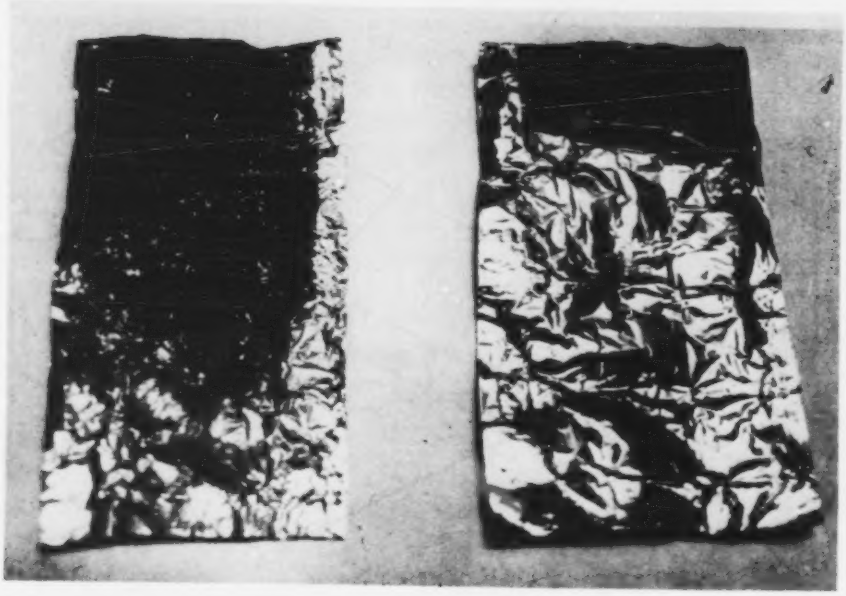

FIGURE 6 Unfolded foils with dust collected in a roof ventilator above an electric arc furnace.

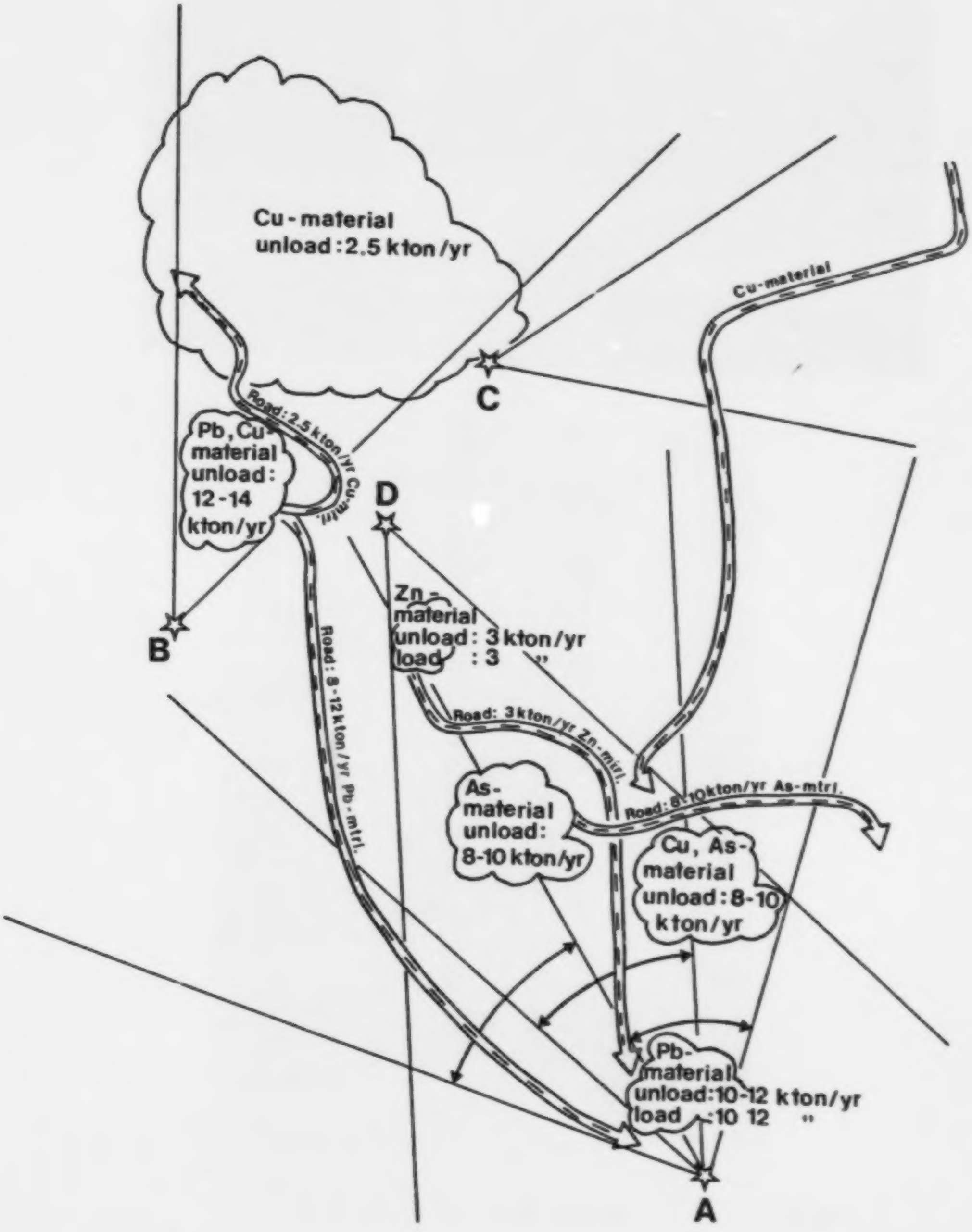
Cu-material unload: 2.5 kton/yr
Cu-material
C
Road: 2.5 kton/yr Cu-mtrl.
Pb, Cu-material unload: 12-14 kton/yr
D
B
Zn-material unload: 3 kton/yr load : 3 "
Road: 8-12 kton/yr Pb-mtrl.
Road: 3 kton/yr Zn-mtrl.
Road: 8-10 kton/yr As-mtrl.
As-material unload: 8-10 kton/yr
Cu, As-material unload: 8-10 kton/yr
Pb-material unload: 10-12 kton/yr load : 10 12 "
A

FIGURE 7 Simplified overview of raw material handling and measurement sectors

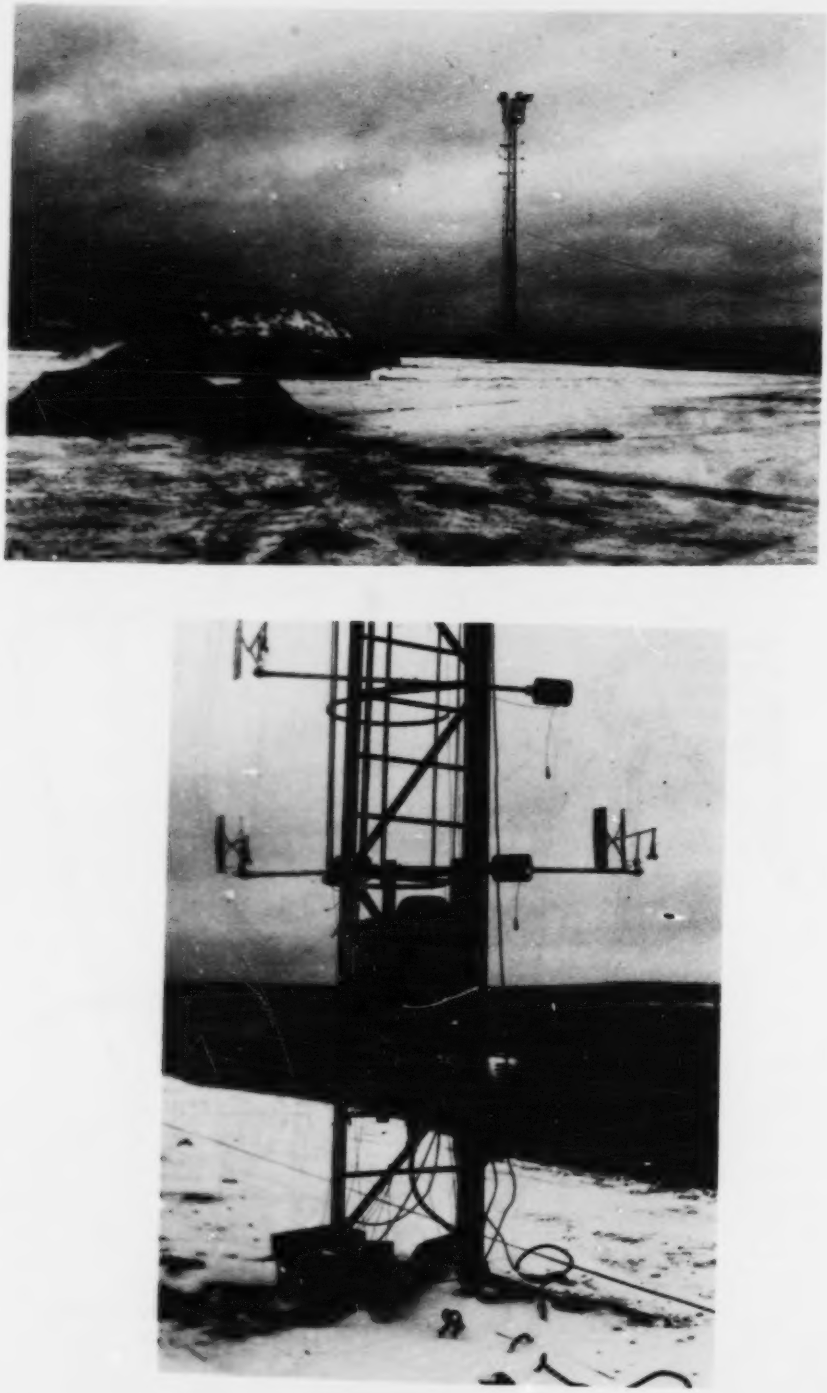

FIGURE 8 Samplers mounted on masts.

ASSESSING HAZARDOUS WASTE TREATMENT FACILITY FUGITIVE ATMOSPHERIC EMISSIONS

By

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ABSTRACT

A program of sampling and analysis for the identification and quantification of atmospheric emissions and the development of emission factors for all aqueous waste storage, treatment, and disposal processes at a hazardous waste management facility has been developed. Samples for atmospheric emission characterization will be obtained via at least two complementary methodologies, wherever possible, as follows. At the facility's aqueous waste receiving and physical/chemical treatment lagoons, composite liquid samples will be obtained for equilibrium vapor analyses, and in situ surface sampling, using an enclosure technique, will be performed. At the aerated biological oxidation ponds, these methods will be supplemented by an emission profiling method.

The organic vapor content of all air samples will be analyzed with a Century Systems Organic Vapor Analyzer (OVA) with a self-contained gas chromatographic/flame ionization detector system. Initally, OVA analyses will be duplicated using a laboratory gas chromatograph/mass spectrometer for verification and calibration of results. Additionally, impinger absorption samples will be collected for the determination of ammonia, amine, and acidic vapor emission rates.

Measured pond and lagoon emission rates will be used to develop emission factors (mass emission rate per unit of surface area), and mass transfer coefficients will be determined for a theoretical emission rate expression which has been developed. Further, sampling results will be used to identify potentially troublesome (e.g., toxic or odorous) emissions from any process. A meteorological monitoring station is also being installed for correlation of meteorological conditions to sampling results and for future analysis and prediction of atmospheric emission problems.

Sampling results are not yet available for discussion; therefore, concentration is given to the details of the planned sampling and analytical program and the computation methodology, for characterizing the facility's waste treatment pond and lagoon emissions.

INTRODUCTION

Hazardous waste management facilities may contain significant sources of both stack or point and fugitive atmospheric emissions, depending upon the nature of the waste materials and the particular processes and operations employed. Methods for measuring point or stack emission rates are well defined, and emissions of many point sources have been fairly extensively quantified. Fugitive emissions, however, have received much less attention and have not been well quantified.

The sampling and analysis program described here has been developed for the identification and quantification of fugitive atmospheric emissions from aqueous hazardous waste treatment processes. The results of this program will be used to develop emission factors and mass transfer coefficients for use in a theoretical emission rate expression which has been developed, and to identify potentially troublesome (e.g., toxic or odorous) emissions. Although a comprehensive program for emission characterization involving all of the treatment, storage, and disposal operations of hazardous waste treatment facilities has been developed, the discussion here concentrates primarily on the aqueous waste ponds and lagoons. Sampling results are not yet available, so this discussion is limited to the details of the planned sampling and analytical program and the emission rate computation methodology.

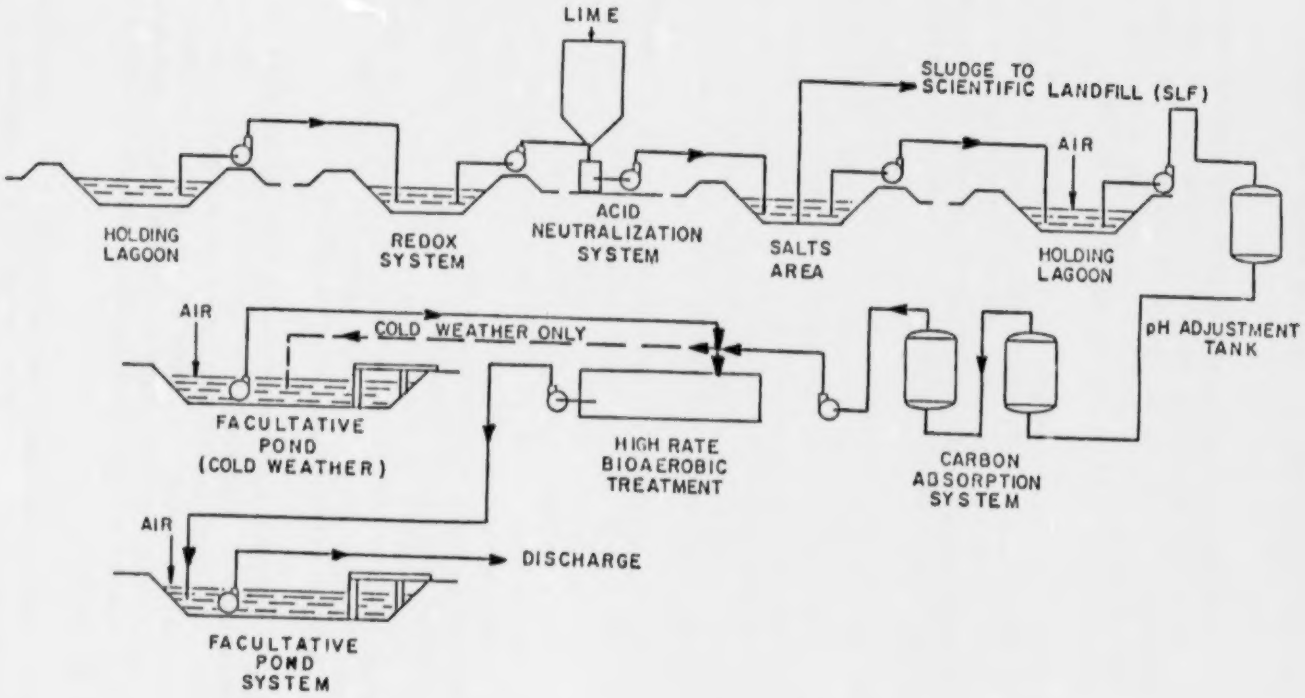
BACKGROUND

Hazardous Waste Management Facility -- Aqueous Waste Treatment Processes/Emissions

The facility for which this atmospheric emission characterization program has been developed is a relatively advanced, comprehensive processing, recovery, and disposal plant for a wide range of liquid and solid hazardous wastes. The capabilities of this facility include the bulk transfer of wastes; solvent and fuels recovery; physical, chemical, and biological treatment of aqueous wastes; and secured scientific landfill of solid material. Since the emphasis of this paper is the characterization of atmospheric emissions from the facility's aqueous waste ponds and lagoons, the aqueous waste treatment system will be reviewed here.

The aqueous waste treatment system consists of four unit operations: (1) chemical oxidation and reduction; (2) neutralization and precipitation; (3) carbon adsorption; and (4) biological treatment (Figure 1). Incoming aqueous wastes are sent to the oxidation-reduction system, consisting of

FIGURE 1


LIME
SLUDGE TO SCIENTIFIC LANDFILL (SLF)
AIR
HOLDING LAGOON
REDOX SYSTEM
ACID NEUTRALIZATION SYSTEM
SALTS AREA
HOLDING LAGOON
pH ADJUSTMENT TANK
AIR
COLD WEATHER ONLY
FACULTATIVE POND (COLD WEATHER)
HIGH RATE BIOAEROBIC TREATMENT
CARBON ABSORPTION SYSTEM
AIR
DISCHARGE
FACULTATIVE POND SYSTEM

AQUEOUS WASTE TREATMENT SYSTEM

three lagoons in series, in which the wastes are chemically oxidized and reduced. Wastes containing reducing agents are sent to one lagoon; wastes high in organic matter or containing oxidizing agents are sent to a second lagoon; and wastes from these two are mixed together into a third lagoon, which is always maintained in a slightly reducing state to promote heavy metal precipitation.

Following oxidation-reduction, the waste enters the neutralization-precipitation system. Here the pH of the waste is increased to approximately 11.5 by the addition of lime in an agitated vessel. The resulting alkaline slurry is then conducted to a gravity separation area, the salts lagoons, where the heavy metals settle out as metal hydroxides.

The supernatant from the salts lagoons is transferred to a holding pond, after which its pH is adjusted to approximately neutral, and it is sent through sand filters prior to treatment in the carbon adsorption system. In the carbon adsorption system, the organic content of the waste, particularly the high molecular weight organics, is reduced substantially.

Following carbon adsorption, the waste enters the biological treatment system. The first stage of biological treatment is a high rate aeration system consisting of a 500,000 gallon tank with a 40 horsepower surface aerator. This is followed by the facultative pond system, consisting of a series of large, aerated ponds, where biological reduction of the waste's organic matter continues. The final step is the storage of the treated wastewater in aerated ponds prior to discharge into natural water bodies.

The many open ponds and lagoons of this aqueous waste treatment system expose large surface areas from which dissolved contaminants may be emitted to the atmosphere. The raw waste contains a wide range of volatile organics, as well as dissolved inorganics, acids, and bases. Oxidation-reduction reactions and changes in pH in the redox and neutralization systems result in the formation and potential volatilization of partially oxidized organic species as well as inorganic gases such as ammonia, amines, and H_2S. Further, in the biological treatment system, the emission potential is enhanced by the aeration of the liquid. Here, volatile organic matter remaining dissolved in the water as well as products of biological degradation of these organics (e.g., amines, ammonia, aldehydes, ketones, alcohols, and H_2S), may be released to the atmosphere.

Due to the widely varying sources of waste handled by this facility, the nature and composition of the waste varies extensively. Wastes received at the aqueous waste treatment system include such materials as the following: acids and alkaline solutions, some of which contain heavy metals; aqueous solutions containing various organic contaminants; and water contaminated with any of a number of potentially hazardous materials such as phenol, PCB, or heavy metals.

Because of this vast variation in waste composition, atmospheric emissions from this sytem cannot be predicted based on the concentrations of specific components of the waste, and a sampling and analysis program for characterizing the emissions cannot be designed for specific chemicals in the entering waste streams. Rather, the prediction of emissions and the design of a sampling program must be comprehensive and generic in nature. Emissions considered must include those categories of classes of materials most likely to be emitted based on (1) their presence in substantial concentrations, either because they are major constituents of the types of waste materials typically treated, or because they are typically formed during biological degradation of these wastes; and (2) their volatility and diffusivity.

Emission Estimating Methodology

A methodology has been developed for estimating atmospheric emissions from aqueous waste ponds and lagoons based on the concentrations, volatilities (as determined by vapor pressure and activity coefficient, or Henry's law constant), and diffusivities of the wastewater contaminants. The methodology is founded upon basic two-phase mass transfer theory, and preliminary values for empirical constants of the methodology's mass transfer expression have been developed from data reported in the literature. Work dealing specifically with the evaporation of volatile components of aqueous waste provided limited data for the computation of wastewater atmospheric emission rates (Bondurant 1973, Englebrecht 1961, Fruman, Gaudy 1961, Ledbetter 1978, Thibodeaux 1971 and 1978, and Tischler). However, a great deal of data, useful for determining mass transfer rates, has been reported in association with related subjects such as evaporation from spills (Wu), evaporation of water from exposed surfaces (Liss 1973, Harbeck 1962), evaporation of components of dilute solutions (Dilling 1977), dissolution of gases into the ocean (Broeker 1974, Liss 1974, National Academy of Sciences 1976, Schooley 1969, Slinn 1978), dissolution of oxygen into water (Owens 1964), and gas scavenging by rain (Hales 1972).

The basic premise of the methodology is that the rate of emission of dissolved materials from the surface of ponds and lagoons is a function of the driving force for mass transfer across the water-air interface. The main bodies of the water and air phases are assumed to be well mixed, so that the water-air interface, considered as a two-layer film, is assumed to offer the primary resistance to the transfer of mass from the liquid to the gas phase, resulting in the concentration profile depicted in Figure 2.

The transfer of mass across the interface may be expressed by applying Fick's first law of molecular diffusion to the two-layer situation as follows:

$$F = K\Delta C = k_L(C_{LB} - C_{LI}) = k_G(C_{GI} - C_{GB});$$

where F is the interfacial flux of mass per unit of surface area, k_L and k_G are the liquid- and gas-phase mass transfer coefficients, and C represents the solute concentration in the bulk liquid (LB), liquid interface (LI), gas interface (GI), and bulk gas (GB). Further, the liquid- and gas-phase mass transfer coefficients may be expressed in terms of molecular diffusivity (D), and the thickness of the interfacial film (Z) as follows:

FIGURE 2

CONCENTRATION GRADIENT FOR MASS TRANSFER ACROSS THE WATER-AIR INTERFACE

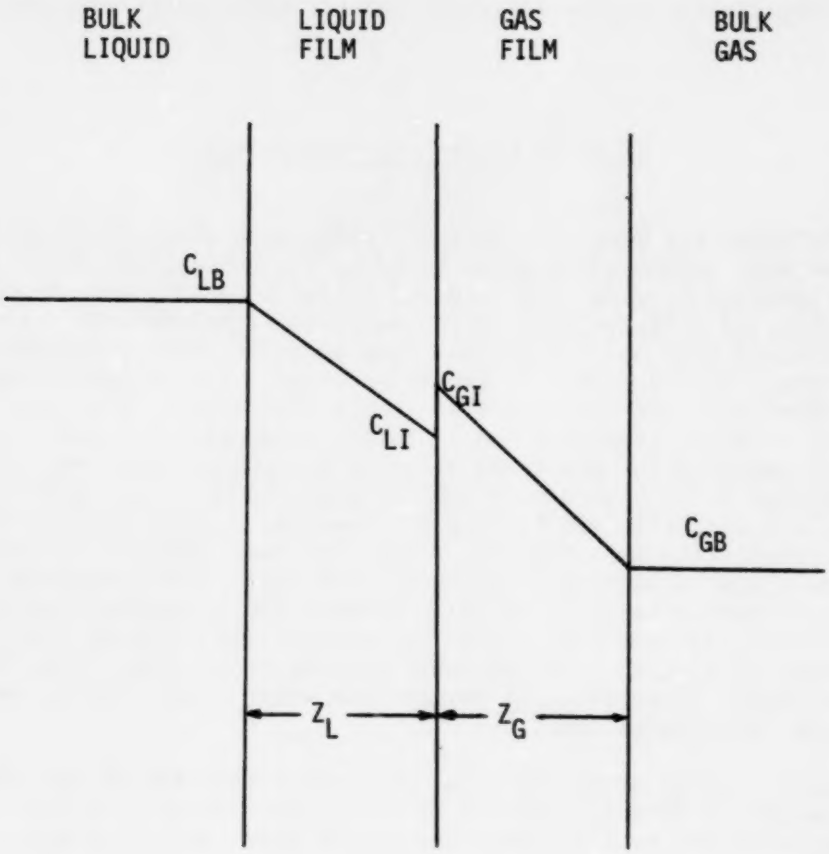

BULK LIQUID
LIQUID FILM
GAS FILM
BULK GAS
C_{LB}
C_{GI}
C_{LI}
C_{GB}
Z_L
Z_G

Figure Notation

C -- Solute Concentration
LB -- Bulk Liquid
LI -- Liquid Interface
GI -- Gas Interface
GB -- Bulk Gas
Z -- Film Thickness

$$k = \frac{D}{Z}$$

The gas film interface concentration may be expressed in terms of the liquid film interface concentration, using an appropriate partition coefficient, M, assumed to be the Henry's law constant or the product of the solute's activity coefficient and vapor pressure, as follows:

$$C_{GI} = MC_{LI}$$

Substitution into the expression for flux, assuming the bulk air phase concentration equals zero, and simplifying, yields the following expression for transfer of mass across the water-air interface:

$$F = k_L C_{LB} \left(1 - \frac{k_L}{k_G M + k_L}\right)$$

The liquid film thickness is not highly variable (National Academy of Sciences 1976), and the liquid diffusivity, which is a function of the system temperature and the solute molecular weight and inter-molecular attraction, may be assumed to be fairly constant for the range of conditions and solutes of concern. Thus, based on published data (National Aceademy of Sciences 1976, Liss 1973 and 1974, Broeker 1974, Thibodeaux 1978, Schooley 1969, Slinn 1978, Owens 1964, Harbeck 1962), a value may be derived for k_L of approximately 3 to 5 X 10^{-3} cm/sec. The variation in the gas phase mass transfer coefficient is much greater, due to the greater variability of gas phase diffusivities and because of the sensitivity of the gas film thickness to environmental conditions, particularly wind speed. Based on limited published data (Liss 1974, Schooley 1969), a first approximation of a mean value may be derived for the gas film thickness of 0.26 cm.

Emissions from aerated surfaces may be treated in a manner similar to the above treatment for quiescent surfaces, by accounting for the increased surface area created by the aerators and the enhancement of the gas film mass transfer coefficient. Data are available for estimating the increased surface area created by aerators (Bondurant 1973), and estimates of mass transfer coefficients for such systems have been developed (Thibodeaux 1978).

As present, however, emission rates may not be predicted with confidence for either quiescent or aerated surfaces of wastewater ponds and lagoons because of the paucity of data for determining mass transfer coefficients for these systems. One purpose of the proposed atmospheric emission sampling program is to furnish these data.

PROCEDURE

Sampling

A number of sampling methodologies were considered for use in the emission characterization program. These included upwind-downwind sampling (Kolnsberg 1976a), a quasi-stack technique (Kolnsberg 1976b), emission profiling (Cowherd 1977), source enclosure methods (Zimmerman 1978, Adams 1979), and vapor space analysis techniques. The program which has been developed involves the use of a vapor space analysis technique in conjunction with an enclosure sampling method for the non-aerated aqueous waste lagoons, and emission profile sampling for the aerated ponds.

Vapor Space Analysis

The vapor space analysis is used to identify and determine the concentrations of species in the vapor phase at equilibrium with the aqueous solutions of concern. This analysis provides for the identification of solutes which are present in solution at sufficient concentration and which are sufficiently volatile to be released from the pond or lagoon into the air above it. Further, since the vapor phase equilibrium concentrations of the solutes are determined, this analysis provides a direct indication of the driving force for mass transfer because it identifies and quantifies the evaporative potential of the volatile species which are of interest and is not confounded by interferences of other materials present.

The first step in performing a vapor space analysis is collecting a composite liquid sample from the pond or lagoon of interest. The sample collection container is filled completely and sealed tightly to prevent the evaporation of volatile components during handling. In the laboratory, the sample is thoroughly mixed and an aliquot of approximately 800 ml is transfered to a 1 liter flask with a side arm. (The flask should be at least three-quarters full). The flask is sealed tightly with a septum, the contents are agitated, and the flask is placed in a 70°F constant temperature bath. After allowing sufficient time for equilibrium between the liquid and gas phase at 70°F to be reached, a micro-liter syringe sample of the vapor is withdrawn.

The gas sample is syringe injected into the carrier gas stream of the (Organic Vapor Analyzer) gas chromatograph (GC). After the chromatogram is obtained, the GC column is backflushed directly to the flame ionization detector chamber, providing a quantitative measurement of any residual compounds in the gas sample. In this way, the total concentration of organic material as well as the concentrations of individual species may be determined. To ensure that the vapor samples analyzed represent equilibrium conditions, gas chromatograms will be run at 15 minute intervals, after an initial equilibrization period of one hour, until constant results are obtained for successive samples.

Surface Enclosure Sampling

Surface enclosure sampling provides data for the determination of the dynamic rate of transfer of material from the liquid surface of a pond or lagoon into the air above it. To obtain a dynamic sample of this air, an air-tight surface enclosure, with a sample outlet and fresh air inlet at opposite ends, is floated on the surface of the water. An air-tight enclosure is created by covering one end of the opening of an inflated truck innertube with translucent plastic, sealed to the tube's perimeter. As the air sample is withdrawn at a constant rate through the sample outlet, purified sweep air enters the opposite end of the enclosure through an inlet tube which projects down to just above the liquid surface. The sweep air is purified prior to entering the enclosure by passing through a dual adsorption column of activated carbon and XAD2, when sampling for organic vapors, and through appropriate absorption solutions, when sampling for ammonia, amines, and H_2S.

For organic vapor analyses, the sample air is drawn directly into the OVA. The gas sampling rate to the OVA is adjusted, while monitoring the total organic vapor concentration, until a concentration of 10-20 ppm is obtained. This concentration is high enough for accurate measurement and low enough so as not to cause vapor phase resistance to mass transfer (the equilibrium partial pressure of volatile species will correspond to a concentration much greater than 20 ppm).

Once the desired flow rate is determined, sampling at this rate is continued until a steady state condition is reached, as indicated by a stable concentration reading. At this point, the flow rate and concentration of total organic compounds are noted, and a portion of the sample being drawn to the OVA is injected into the GC column for identification and quantification of the organic species present. A surface-based emission rate is determined from the data obtained by dividing the product of the gas sample rate and the measured concentration by the area of the liquid surface exposed to the inside of the enclosure. That is:

Emission Rate Per Unit of Surface Area = (Gas Sampling Flow Rate) X (Sample Concentration)/(Surface Area Covered by Enclosure).

The dynamic emission rate can be correlated to equilibrium vapor phase concentration data, determined via vapor space analysis, for a determination of the resistance to mass transfer posed by the liquid and gas interfacial films, or, conversely, the interfacial mass transfer coefficients.

Profile Sampling

Because the surface enclosure method cannot be used where the surface is disrupted by the action of aerators, an alternative sampling approach employing a perimeter or downwind air sampling technique must be used at the aerated biological oxidation ponds. For this program a perimeter profile sampling technique was selected.

In profile sampling, the concentrations of contaminants are measured at an array of points in the source emission plume as it passes some downwind location; in this case, the source perimeter. From these measurements, a vertical plume concentration profile can be developed. Initially, screening is performed, using the total organic vapor analysis capability of the OVA to determine the necessary extent of the vertical sample point array and the sample point spacing needed to develop a meaningful profile. Then, at each sampling point, samples are drawn into the OVA for total organic vapor analysis and for GC determination of the organic components. Additionally, samples are collected in appropriate absorption solutions for analyses of inorganic vapor emissions. An upwind sample is taken in each case so that background contaminants levels can be accounted for.

The vertical plume profile is plotted and integrated over the vertical extent of the plume in order to determine the average plume concentration. The emission rate per unit of surface area can then be determined by multiplying the average plume concentration by the amount of diluting wind which crossed a one unit wide vertical cross section of the plume (i.e., wind speed times the vertical extent of the plume) and dividing by the pond surface area over which the one unit width column of wind traveled (i.e., pond width). That is:

Emission Rate Per Unit of Area = Average Plume Concentration X Wind Speed X Vertical Extent of the Plume ÷ Pond Width.

Sample Analysis

Organic Vapor Analysis

A portable Organic Vapor Analyzer (OVA) produced by Century Systems Corporation will be used for determining the total concentration of organic material and the concentrations of specific organic compounds in gaseous emission samples. The portable OVA is designed to measure small concentrations (1-10,000 ppm) or organic material in air. The OVA uses a hydrogen flame ionization detector (FID) which has been used for many years as a detector for organic compounds, and it has a built-in gas chromatograph for separation of the components of sampled gases. The portability of the OVA coupled with its intrinsic safety make it an ideal instrument for the proposed field work. (The OVA is certified intrinsically safe by Factory Research Corporation for Plot One, Division One, Groups A, B, C, and D hazardous environments).

The FID system used in the OVA consists of a diffusion flame of pure hydrogen which is free of ions and is thus nonconducting. However, when a sample of organic material is introduced into the flame, ions are formed and the flame becomes conductive. The conductivity of the flame can then be measured. The amount of conductivity that the flame exhibits with the introduction of organic compounds is related to many parameters, but is thought to be primarily based on the number of carbon atoms present and the efficiency of combustion.

In the typical laboratory FID, the sample to be analyzed is entirely mixed with the hydrogen prior to introduction to the burner. This premixing of the sample with the hydrogen does not occur in the OVA. In the OVA, the sample is brought in with the combustion air. The sample contained in the combustion air is introduced into the combustion/detection chamber through a porous bronze filter which disperses the air and organic compounds around the hydrogen flame.

This method of introducing the sample to the hydrogen flame modifies the typical ion formation process and consequently changes the OVA's FID response to various compounds from that of a conventional FID. In the usual laboratory FID, a normal C_3 would have a response of three times the methane response (for the same concentration) and a normal C_6 would have a response of six times that of methane. The OVA FID, however, has a response for nearly all commonly encountered hydrocarbons of between 50% and 150% the response for methane.

The precise reason for the difference in response between the OVA and other FID's has not been completely determined. One hypothesis is that the size of the reaction envelope and the energy available from the hydrogen flame are altered by intoducing the sample at the periphery of the flame reaction zone. This allows for less contact time, which reduces the number of ions formed, and consequently changes the response mechanism.

The Century Systems OVA, which will respond to almost all organic compounds, may be calibrated with hexane. However, since the response of the OVA differs somewhat for the various compounds, it is best to calibrate the instrument with the organic compounds that are expected to be encountered in the field. The basic method for developing a calibration curve consists of recording the response of the OVA to a range of concentrations of the expected organic gases. The OVA responses to the known hydrocarbon concentrations are then plotted to obtain a calibration curve for the test mixture.

The compositions of the test mixtures used for initial calibrations will be determined from the presence of volatile organics in the wastes received and from GC/mass spectrometer analyses of equilibrium vapor samples of pond and lagoon wastewater. During the sampling program, any additional peaks which occur, which were not present in the original test mixtures, will be evaluated based on their relation to known peak locations and heights, to the extent possible. Recurring unknown peaks will be evaluated by performing additional GC/mass spectrometer analyses, as needed.

Inorganic Vapor Analysis

Inorganic gases do not contain carbon atoms and, therefore, they are not detected by the OVA FID. Further, because the anticipated inorganic constituents of waste treatment pond and lagoon emissions are highly reactive, they are not well suited to analyses, such as GC/mass spec, which require the collection of neat samples in glass bombs or sample bags. Therefore, absorption sampling will be used for collecting air samples for the analysis of inorganic vapor constituents by wet chemical methods. Although many types of wash bottles are available for air sampling, impingers are recommended for collecting readily absorbable gases which rapidly dissolve in the washing liquid. For the proposed program, a series of Greenburg-Smith impingers are to be used. A constant flow rate pump is used to draw air through these impingers at a rate of up to 1 cubic foot per minute (28 liters per minute) for the desired sampling duration (typically 30 to 60 minutes). A 50 milliter aliquot of washing solution is typically employed in each impinger. Effective washing of the air by the absorption solution is enhanced by the small diameter of the narrow end of the impinger inlet tube (2.3 mm) and the proximity of the inlet to the base (5 mm).

Examples of analytical methods for the inorganic vapors of concern, selected based on sensitivity and specificity (Leithe 1971 and Ruch 1970), are as follows:

Ammonia - Indophenol Reaction (Leithe 1971)

Determination Method - spectrophotometric
Absorption Solution - 0.01N H_2SO_4
Sensitivity - ppb range
Interference - monoalkylamines

- Nessler's Reaction (Elkins)

Determination Method - spectrophotometric
Absorption Solution - sulfuric acid
Sensitivity - 3 ppm
Interference - any material producing ammonia

- As Trichloramine (Zitomer 1962)

Determination Method - spectrophotometric
Absorption Solution - distilled water
Sensitivity - 10 - 300 ppm
Interferences - amines

- Phenol - Hypochlorite Reaction (Weatherburn 1967)

Determination Method - spectrophotometric
Absorption Solution - distilled water
Sensitivity - suitable for air pollution work
Interferences - amines

Aliphatic Amines - Acylation with Cinnamic Anydride (Hong 1968)

Determination Method - spectrophotometric
Absorption Solution - acetonitrile solution
Sensitivity - ppm level
Interferences - none of concern

Aromatic Amines - With 9-Chloroacridine (Stewart 1969)

Determination Method - spectrophotometric
Absorption Solution - ethyl alcohol
Sensitivity - suitable for air pollution work
Interferences - primary amines

Sulfide - N,N - dimethyl-p-phenylenediamine (Jacobs 1967)

Determination Method - spectrophotometric
Absorption Solution - alkaline cadmium sulfate
Sensitivity - ppm range
Interferences - none of concern

Hydrogen Chloride - Silver Nitrate Titration (Hanson 1965)

Determination Method - titration
Absorption Solution - distilled water
Sensitivity - 2.5 ppm
Interferences - halides

DISCUSSION AND CONCLUSIONS

The proposed sampling program will provide a comprehensive characterization of the organic and inorganic vapor emissions from aqueous hazardous waste physical/chemical treatment lagoons and aerated biological oxidation ponds. Further, the organic vapor emission data will be used to develop organic vapor emission factors for wastewater ponds and lagoons.

The use of complementary sampling and analysis methods will provide for the verification of results. Further, complementary sampling will furnish data for determining both the driving force for mass transfer across the water-air interface and the dynamic mass transfer rate (emission rate), so that empirical mass transfer coefficients can be evaluated.

The driving force for mass transfer can be determined from the equilibrium vapor concentration data from the vapor space analyses. A further value of this analysis technique is that it provides a relatively concentrated gas sample so that organic components of concern can be detected and measured accurately.

The dynamic emission rate may be assessed via surface enclosure, exposure profiling, or upwind-downwind sampling. Surface enclosure sampling provides certain advantages over sampling performed at the perimeter or downwind of an aqueous pond or lagoon. The concentrations of the components of interest in the gas sampled can be varied by varying the rate of enclosure sweep gas, and a concentration suitably high for accurate instrumental analysis can be obtained. In contrast, concentrations at perimeter or downwind sampling points will be much lower. Further, the concentrations of downwind samples are affected by the wind speed and direction and by dispersion, which is a function of atmospheric stability. These meteorological parameters introduce sources of error in relating measured downwind concentrations to surface emission rates.

On the other hand, by enclosing the liquid surface, the experimenter is creating an artificial situation and must guard against the introduction of errors due to consequent effects. The enclosure will stifle the natural escape of heat from the surface, so the sampling period must not be of so long a duration nor the sweep gas of so low a flow rate as to allow heat to build up within the enclosure. Further, the sweep gas rate must be great enough that equilibrium between the components in the liquid and vapor phase is not reached, as this would result in the computation of artificially low emission rates. However, the rate of sweep gas must not be so high as to disturb the liquid surface, artificially inducing volatilization, nor so high that the concentrations of gaseous contaminants are too low to be measured accurately.

Where the surface enclosure technique cannot be used because of the disturbance of the liquid surface from the action of aerators, an alternative method must be employed. For this purpose, profile sampling at the source perimeter offers certain advantages over upwind-downwind sampling. Since samples are obtained closer to the source (i.e., at the source perimeter rather than at some downwind distance), the concentrations of contaminants from the surface will be higher and, thus, can be measured more accurately. Further, although the results are sensitive to wind speed and direction and atmospheric dispersion, the effects of these factors are not as great as they are for the upwind-downwind method.

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RESULTS OF FUGITIVE EMISSION MEASUREMENTS AT REFINERIES AND CURRENT ACTIVITIES IN PETROCHEMICAL UNITS

by

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ABSTRACT

Final results of fugitive emissions monitoring in petroleum refineries are presented as a series of emission factors for valves, flanges, pump seals, compressor seals, relief valves and drains. The emission factors appear to be dependent on the type of service in the line, consequently the emission factors have been developed for gas/vapor, light liquid and heavy liquid service. No dependency on temperature, pressure or line size was noted. Extensive quality control data allowed the calculation of confidence intervals for all emission factors. Correlations between a hydrocarbon "sniffer" value and measured mass emissions rates in pounds per hour are given.

Currently EPA is sponsoring studies in the synthetic organic chemicals manufacturing industry. The current program includes both screening and sampling selected valves and pumps and screening all "baggable" sources in a variety of chemical manufacturing units. The screening studies are being conducted by four separate EPA contractors, Radian, PEDCo, TRW and Acurex with Radian doing all data reduction. Screening data for target chemicals are being obtained from at least two different sites if possible. Sampling data is being obtained for three chemicals at two sites each. Correlations between the hydrocarbon "sniffer" value and the mass emission rate are being developed. Studies of the effect of maintenance on leak rate for valves are also being conducted. Hydrocarbon "sniffer" response factors are being developed for over 100 chemicals with respect to known concentrations of methane.

The intent of this paper is twofold: first, to discuss the final results of the recently completed fugitive hydrocarbon emission portion of an EPA sponsored Petroleum Refinery Assessment Program. Secondly, to discuss a program which is just beginning to study fugitive emissions in various processes of the synthetic organic chemical manufacturing industry (SOCMI). Thus, in Part 1 of this paper we will be discussing final results, while in Part 2 we will be discussing philosophy and design.

Part 1: Results of Fugitive Hydrocarbon Emission Measurements in the Refining Industry

Study Design

The study was designed to include a representative portion of the United States petroleum refining industry for an examination of fugitive emissions from point sources including valves, pump and compressor seals, drains, relief valves and flanges. In the design of the study, the variables of refinery age, refinery size, and refinery location were carefully considered. Thirteen refineries across the United States were selected for the study. They ranged from less than ten years old to nearly 100 years old. The U. S. was divided into four primary geographical areas, that is, the Northeast, Southwest, Midwest, and the West coast, where the bulk of the petroleum refining activity is conducted. At least three refineries were chosen in each of these geographical areas and within each area at least one new and one old refinery and one large and one small refinery were selected. For each fugitive source to be sampled, several variables were considered to be important in selecting those fittings to be tested. Table 1 shows the type and range of variables which were used in developing the sampling matrix for each type of fugitive emission source. Those fittings selected for inclusion in the study were chosen from P&ID diagrams, sight unseen, by Radian engineers, then located in the refinery, screened with a portable hydrocarbon detector, and eventually bagged or tented for actual mass emission rate measurements.

Results

Table 2 presents the results of the fugitive emission measurements by source type. As indicated in the table, the stream service for the various sources proved to be the major source of variation. Types of service were divided into gas vapor streams, light liquid or two-phased streams and heavy liquid streams. The dividing line between light liquid and two-phased streams and heavy liquid streams proved to be at the approximate volatility of kerosene. Valves in hydrogen service were streams which were at least 50 percent hydrogen with the remainder being hydrocarbons. Open ended valves were also singled out. These are valves primarily used for quality control sampling purposes within a refinery unit. The values shown in the table for pump and compressor seals are expressed per seal rather than per pump or per compressor. The emission factor for compressor seals was the largest of any of the emission factors and the percent of compressor seals leaking was the largest of the percentages for any of the sources. Conversely, the percent of flanges leaking was the smallest of any of the sources and its emission factor was also the lowest. Expanding this data to an entire refinery would show that valves are the most significant of all of the leaking sources because of their number, while flanges are the least significant of all leaking sources.

TABLE 1. RANGE OF CHOICE VARIABLES FOR SCREENED BAGGABLE SOURCES

Baggable Source	Choice Variable	Variable Ranges for Screened Sources
Valves	Pressure	-10 - 3000 psig
	Temperature	-190 - 925°F
	Fluid State	Gas, Liquid, 2-phase
	Service	In-line, Open-ended
	Function	Block, Throttling, Control
	Size	0.5 - 36 inches
Flanges	Pressure	-14 - 3000 psig
	Temperature	-30 - 950°F
	Fluid State	Gas, Liquid, 2-phase
	Service	Pipe, Exhanger, Vessel, Orifice
	Size	1 - 54 inches
Pump Seals	Pressure	0 - 3090 psig
	Temperature	0 - 800°F
	Capacity	0 - 100,000 gpm
	Shaft Motion	Centrifugal, Reciprocating
	Seal Type	Mechanical Seal, packed seal
	Liquid RVP	Complete range
Compressor Seals	Pressure	0 - 3000 psig
	Temperature	40 - 300°F
	Shaft Motion	Centrifugal, reciprocating
	Seal Type	Packed, labyrinth, mechanical
	Lubrication Method	Hydrocarbon lubricant
	Capacity	0.06 - 66.0 MMSCFD
Drains	Service	Active, Wash-up
Relief Valves	Pressure	0 - 1350 psig
	Temperature	40 - 1100°F
	Fluid	Gas, Liquid

TABLE 2. SUMMARY STATISTICS AND ESTIMATED VAPOR EMISSION FACTORS FOR NONMETHANE HYDROCARBONS FROM BAGGABLE SOURCES

Source Type	Number Screened	Number Leaking	Percent Leaking	95% Confidence Interval for Percent Leaking	Emission Factor Estimate (lb/hr/source)	95% Confidence Interval for Emission Factor (lb/hr/source)
Valves						
Gas Vapor Streams	563	154	27.4	(24, 31)	0.059	(0.030, 0.110)
Light Liquid/Two-Phase	913	330	36.1	(33, 39)	0.024	(0.017, 0.036)
Heavy Liquid	485	32	6.6	(4, 9)	0.0005	(0.0002, 0.0015)
Hydrogen	135	59	43.7	(35, 52)	0.018	(0.007, 0.045)
Open-Ended Valves	129	30	23.3	(16, 31)	0.005	(0.0016, 0.016)
Pumps						
Light Liquid Streams	470	296	63.0	(59, 67)	0.25	(0.16, 0.37)
Heavy Liquid Streams	292	66	22.6	(18, 27)	0.046	(0.019, 0.11)
Drains	257	49	19.1	(14, 24)	0.070	(0.023, 0.20)
Flanges	2094	62	3.0	(2, 4)	0.00056	(0.0002, 0.0025)
Relief Valves	148	58	39.2	(31, 47)	0.19	(0.070, 0.49)
Compressors						
Hydrocarbon Service	142	102	71.8	(64, 79)	1.4	(0.66, 2.9)
Hydrogen Service	83	69	83.1	(75, 91)	0.11	(0.05, 0.23)

The distribution of leak rates was another important result of the study. The study results indicate that the majority of sources leak at a very low level and that the significant contributions to the emission factor come from those few sources leaking at high rates. This is illustrated in Table 3 for valves in gas/vapor service, where it is shown that of all the valves in the study, seven of them leaked at greater than one pound an hour and that these seven valves contributed 70 percent of the total mass of the leak. Figures 1 and 2 provide the same information in graphical form relating screening value to percent of sources and percent of emissions, respectively.

Figure 3 shows a nomograph for predicting total nonmethane leaks from screening values for valves in gas/vapor service. This demonstrates that within reasonable confidence limits, the screening value obtained with a hydrocarbon detector can be correlated to mass emission rates for a group of valves. This correlation should prove to be a valuable tool for both maintenance and regulatory activities. The nomograph in Figure 4 demonstrates the same type of relationship for valves in light liquid service. Similar nomographs have been developed for all of the source types investigated during this program. It should be stressed that these nomographs are not meant for direct point by point correlation of single valves, but rather apply to the mean of a number of sources.

Correlations

In Table 4 the correlation coefficients between operating/design variables and leak rate are presented. As you can see, the correlation coefficients presented in the table are by and large rather small. They are, however, statistically significant in those cases where they have been denoted by an asterisk. Even though some of the correlations were statistically significant, no discernible pattern emerges relating leak rate to process/design variables for all sources.

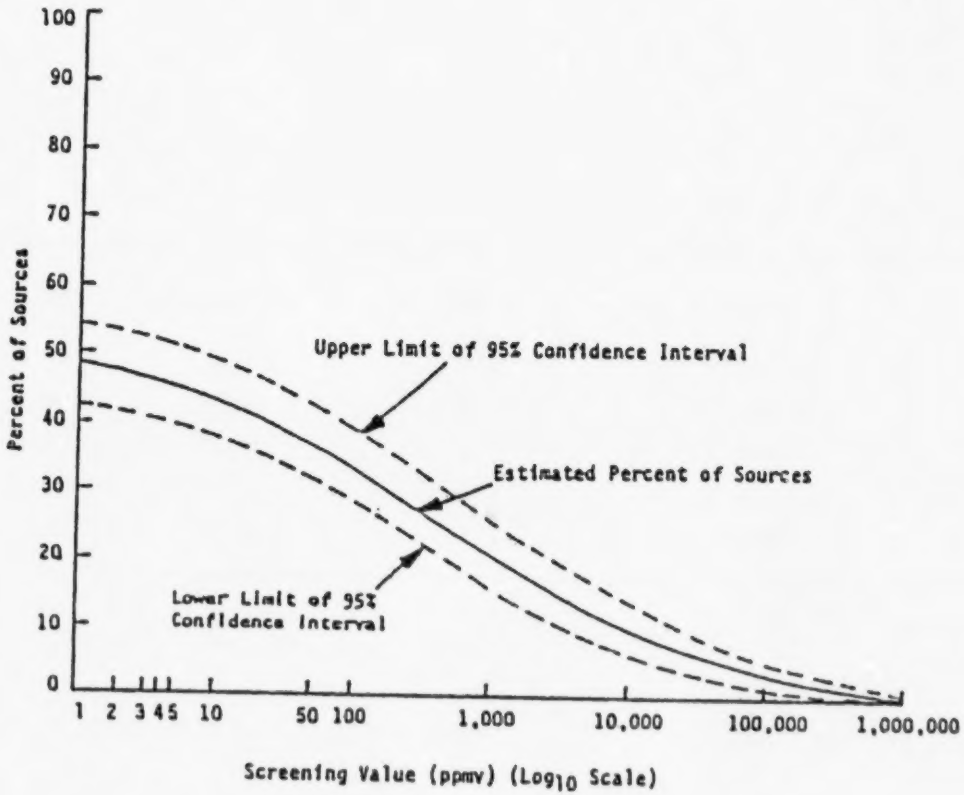
Figures 5 - 7 are schematic plots demonstrating the lack of variation in emission rates in relation to some of the parameters examined in the study. Figure 5 shows the data for pumps with single and double seals, and indicates little difference in the mass emission rate on the basis of seal type. However, there may be some service severity factor which causes the apparent lack of correlation. A service severity factor was not anticipated during the study, thus no data are currently available for ready review. In Figure 6 the same type of information for single seals and double seals is presented for compressors. Once again the cells overlap and the means are extremely close together. Figure 7 examines the block and control function of valves, and again, it is demonstrated that there is very little difference between the mass emission rates in any type of stream between block and control valves. Figure 8 shows the relationship between leak rate and diameter for compressor seals, and again it should be noted that the correlation is poor. Figure 9 shows leak rate versus pressure for compressor seals and again the relationship is poor.

Finally, in Figure 10 the variation in a given leak rate as the function of time is presented. This figure demonstrates the reason for wide confidence intervals in many of the sources and illustrates the difficulty which will be encountered in both maintenance and regulatory activities. As one can see on the right hand portion of the figure, the leak rate in pounds

TABLE 3. DISTRIBUTION OF NONMETHANE HYDROCARBON LEAK RATES

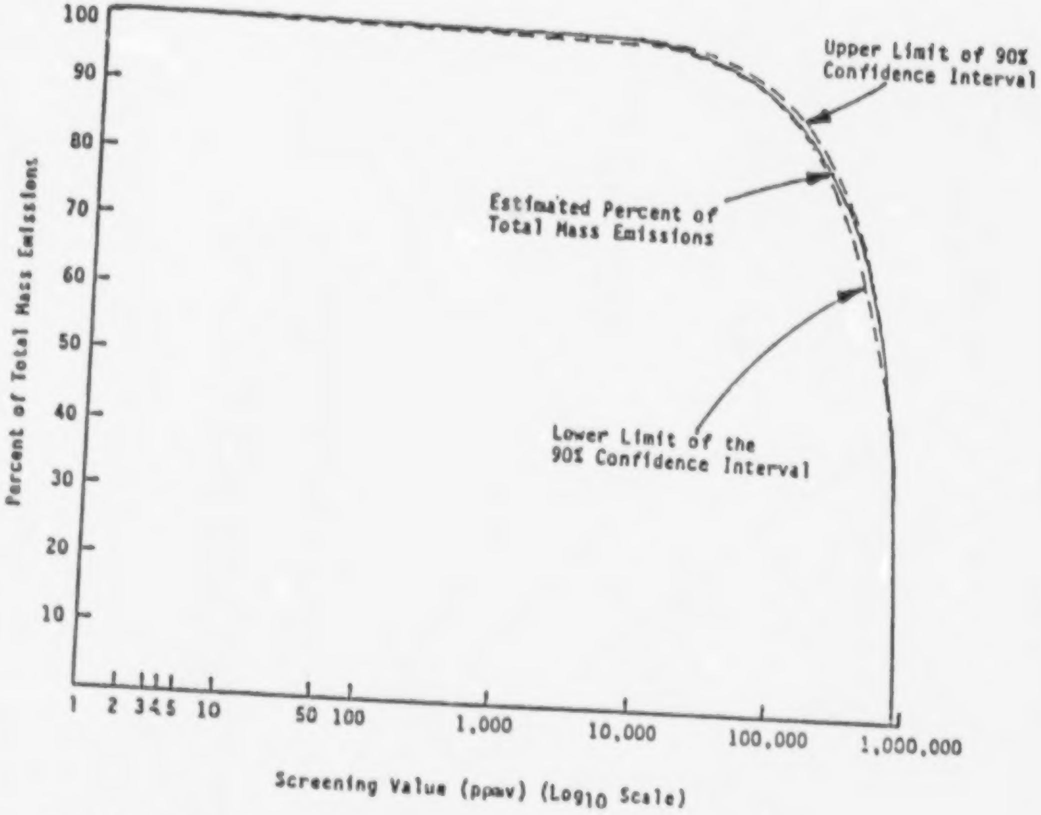
Values, Gas/Vapor Streams
(563 Screened)

Leak Range (lb/hr)	Leaking Sources Within Range			Total Leakage Within Range	
	No.	% of Leaking Sources	% of Total Sources Screened	Total Leakage (lb/hr)	% of Total Source of Leakage
1.0	7	4.6	1.2	17.7654	70.0
0.1 - 1.0	18	11.7	3.2	5.9187	23.3
0.01 - .1	43	27.9	7.6	1.4867	5.9
0.001 - 0.01	49	31.8	8.7	0.2052	0.8
0.00001 - 0.001	37	24.0	6.6	0.0133	0.1
	154	100%	20.3%	25.3893	100%



Percent of Sources - indicates the percent of sources with screening values greater than the selected value.

Figure 1. Cumulative Distribution of Sources and Total Emissions By Screening Values for Valves - Gas/Vapor Streams



Percent of Total Mass Emissions - indicates the percent of total emissions attributable to sources with screening values greater than the selected value.

Figure 2. Cumulative Distribution of Source and Total Emissions By Screening Values for Valves - Gas/Vapor Stream

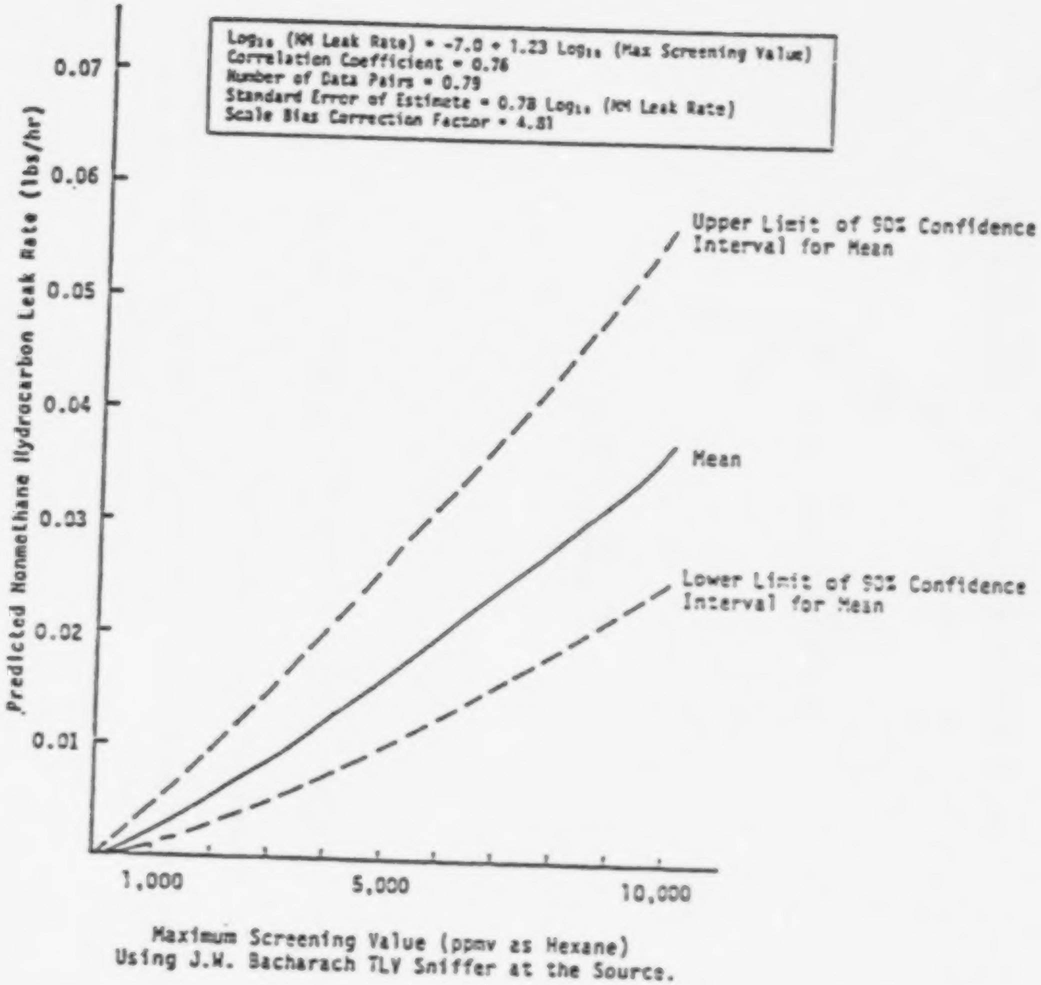


Figure 3. Nomograph for Predicting Total Nonmethane Hydrocarbon Leak Rates from Maximum Screening Values - Valves, Gas/Vapor Streams

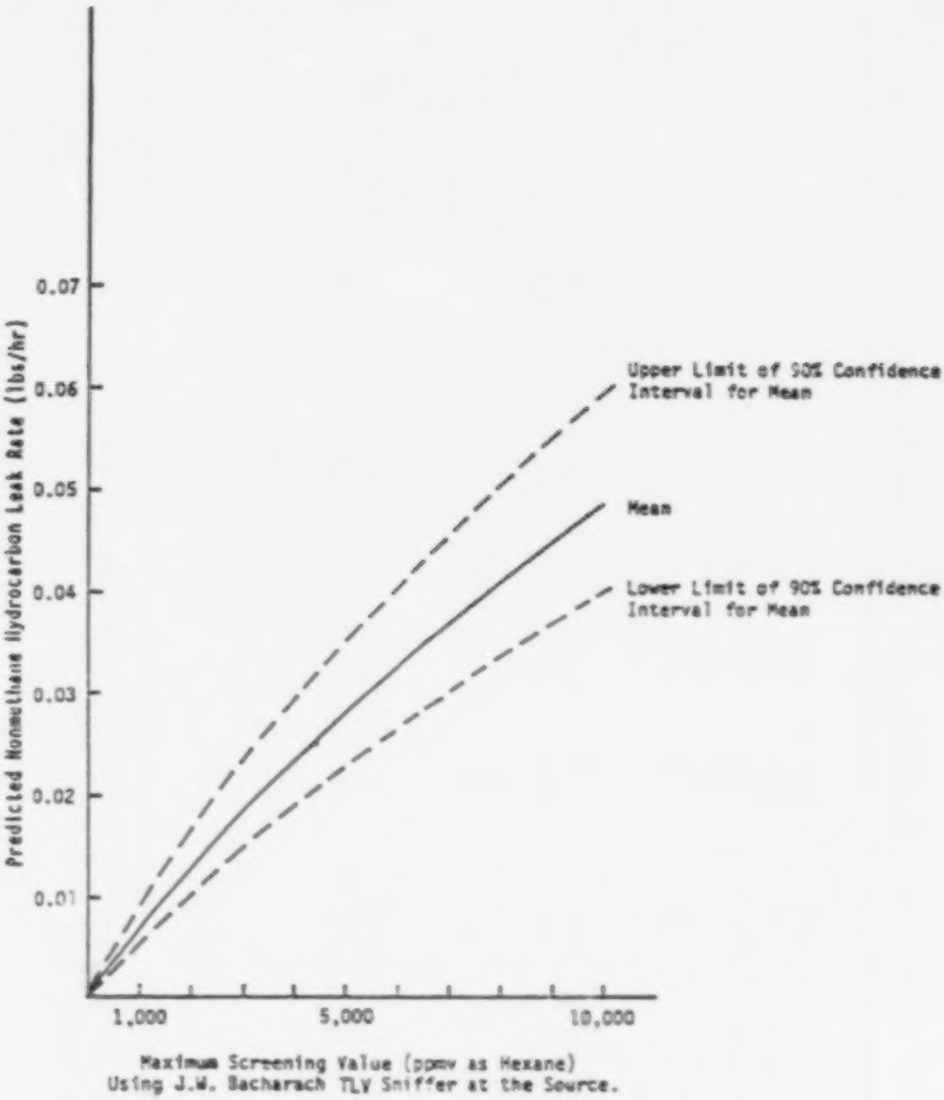


Figure 4. Nomograph for Predicting Total Nonmethane Hydrocarbon Leak Rates from Maximum Screening Values - Valves, Light Liquid/Two-phase Streams

TABLE 4. CORRELATIONS BETWEEN CONTINUOUS VARIABLES AND LOG_{10} LEAK RATE

	PRESSURE	TEMPERATURE	AGE	LINE SIZE	DIAMETER	AREA	RPM	CAPACITY	LOAD	STROKE LENGTH
VALVES										
Gas/Vapor Streams	.230*	.077	.263*	.150*	-	-	-	-	-	-
Light Liquid Streams	.103*	.051	.096	.143*	-	-	-	-	-	-
Heavy Liquid Streams	-.351*	.144	.220	.046	-	-	-	-	-	-
Hydrogen Service	-.088	.129	-.531*	.288*	-	-	-	-	-	-
Open-Ended	.236	.242	.230	-.078	-	-	-	-	-	-
PUMP SEALS										
Light Liquid Service	.088	-.012	.062	-	.021	-	-.064	-	-	-
Heavy Liquid Service	.097	-.098	.237	-	.128	-	-.182	-	-	-
FLANGES	.072	.021	-.180	.336*	-	-		-	-	-
COMPRESSOR SEALS										
Hydrocarbon Service	.346*	.218*	.105	-	.278*	-	-.143[a]	-.138	-.087	-.012
Hydrogen Service	.398*	.312*	.052	-	.343*	-	-.034	.218	-.099	-.074
DRAINS	-	-.408*	-	-	-.039	-.191	-	-	-	-
RELIEF VALVES	.045	.096	-	-.075		-	-	-	-	-

*Correlation Coefficient statistically different from zero ($P > .90$).

[a] Log_{10} RPM was correlated with log_{10} leak rate.

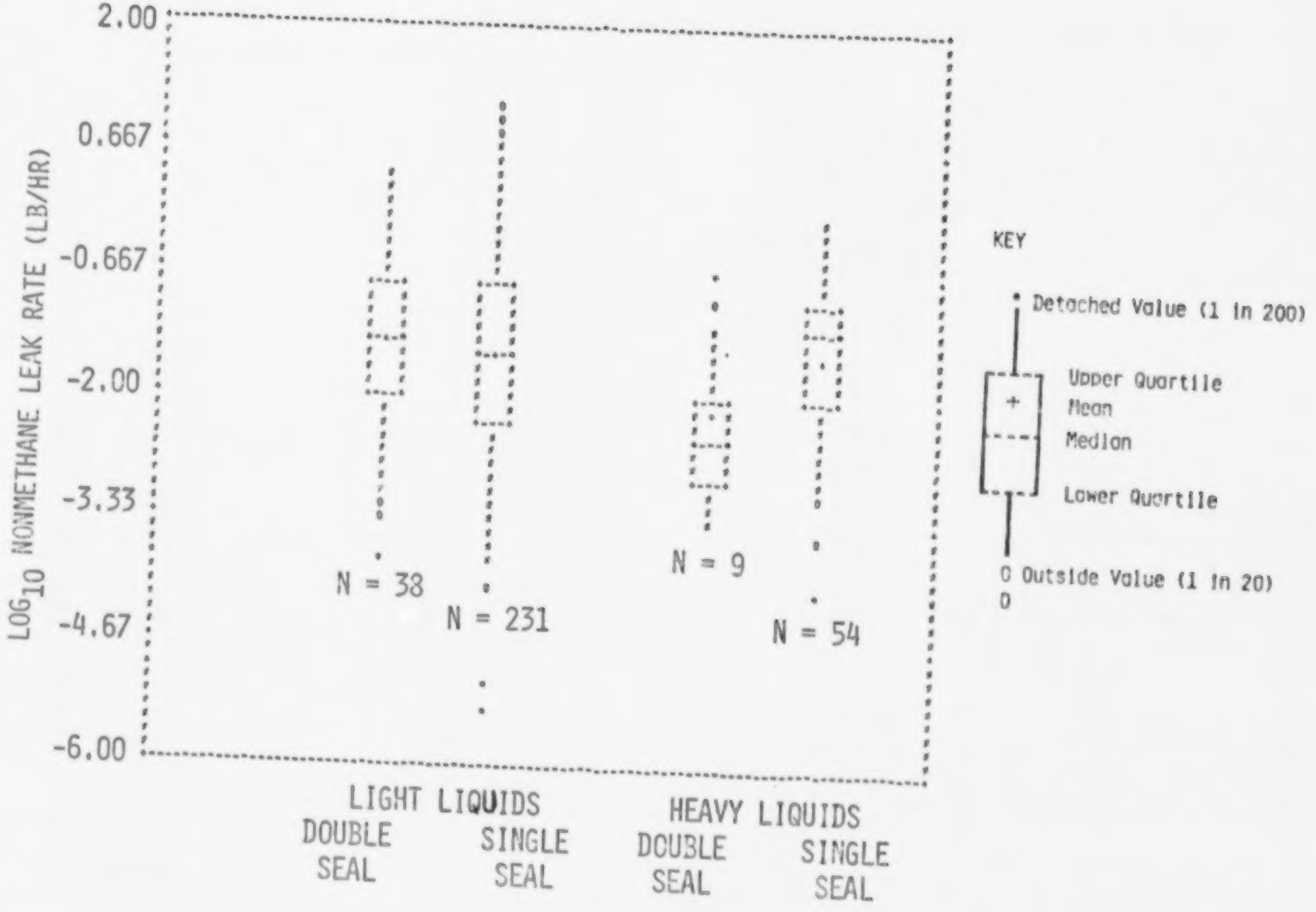


Figure 5. Schematic Plot for Pumps by Seal Variables

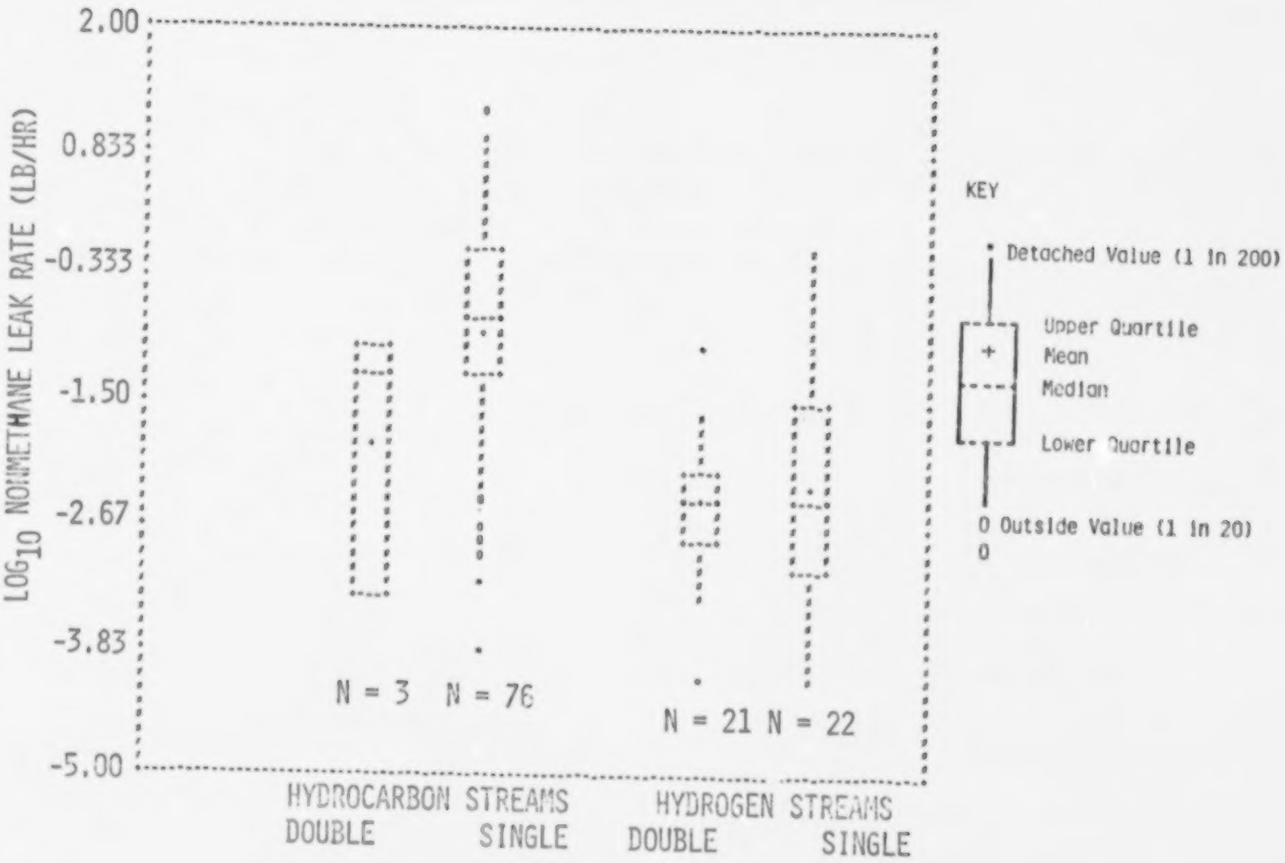


Figure 6. Schematic Plot for Compressor Seals by Single/Double Seal Variable

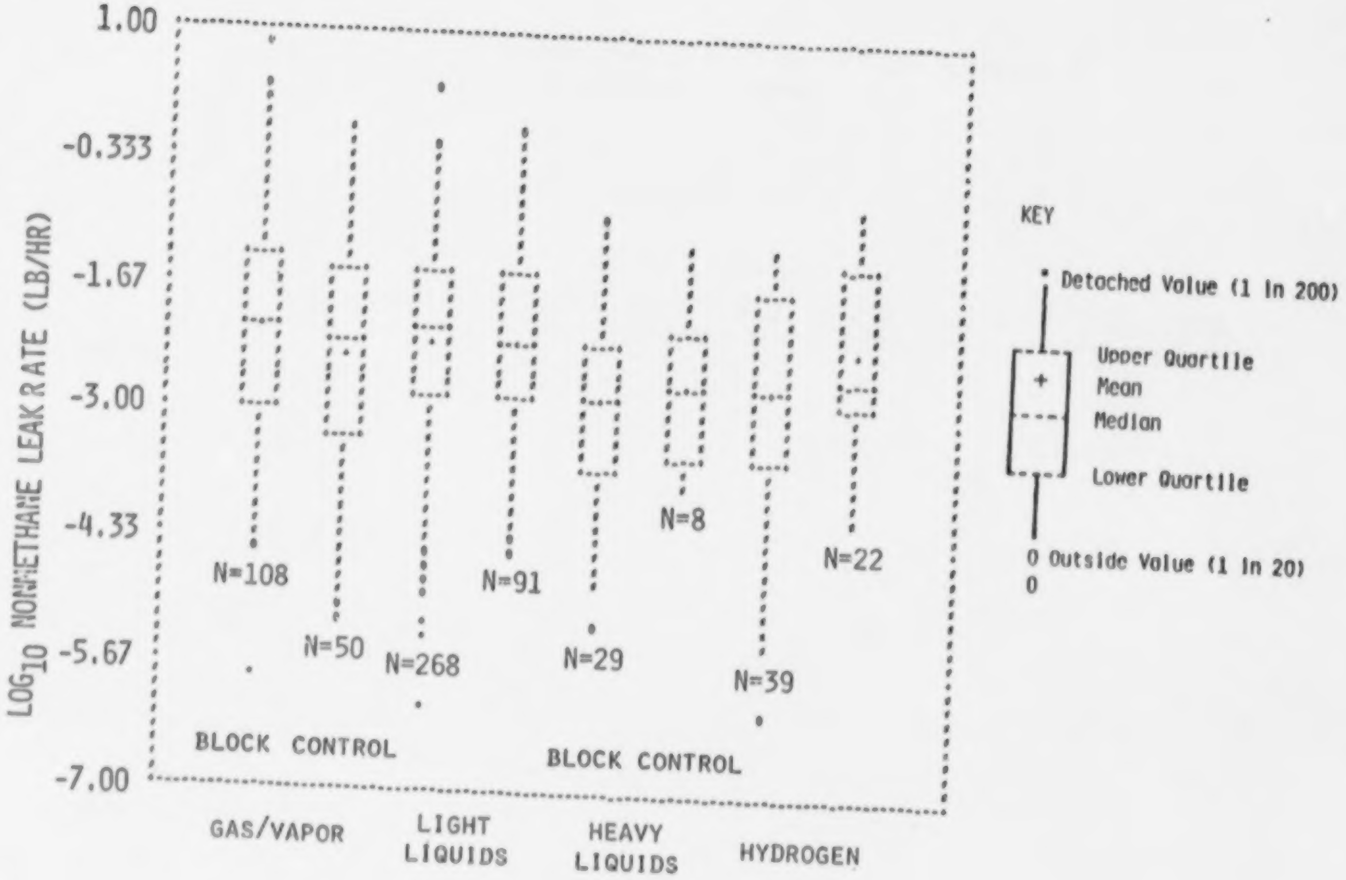


Figure 7. Schematic Plot for Valves by Block/Control Variable

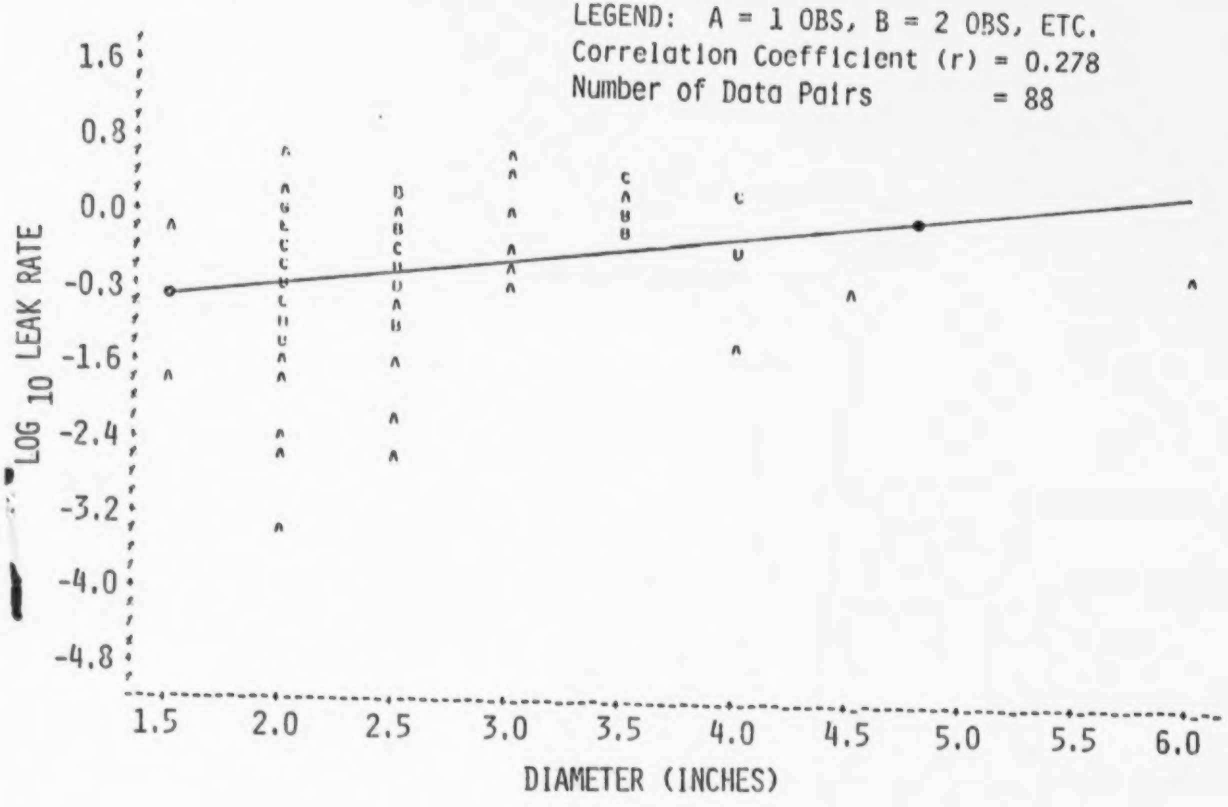


Figure 8. Leak Rate vs. Diameter -
Compressor Seals, Hydrocarbon Service

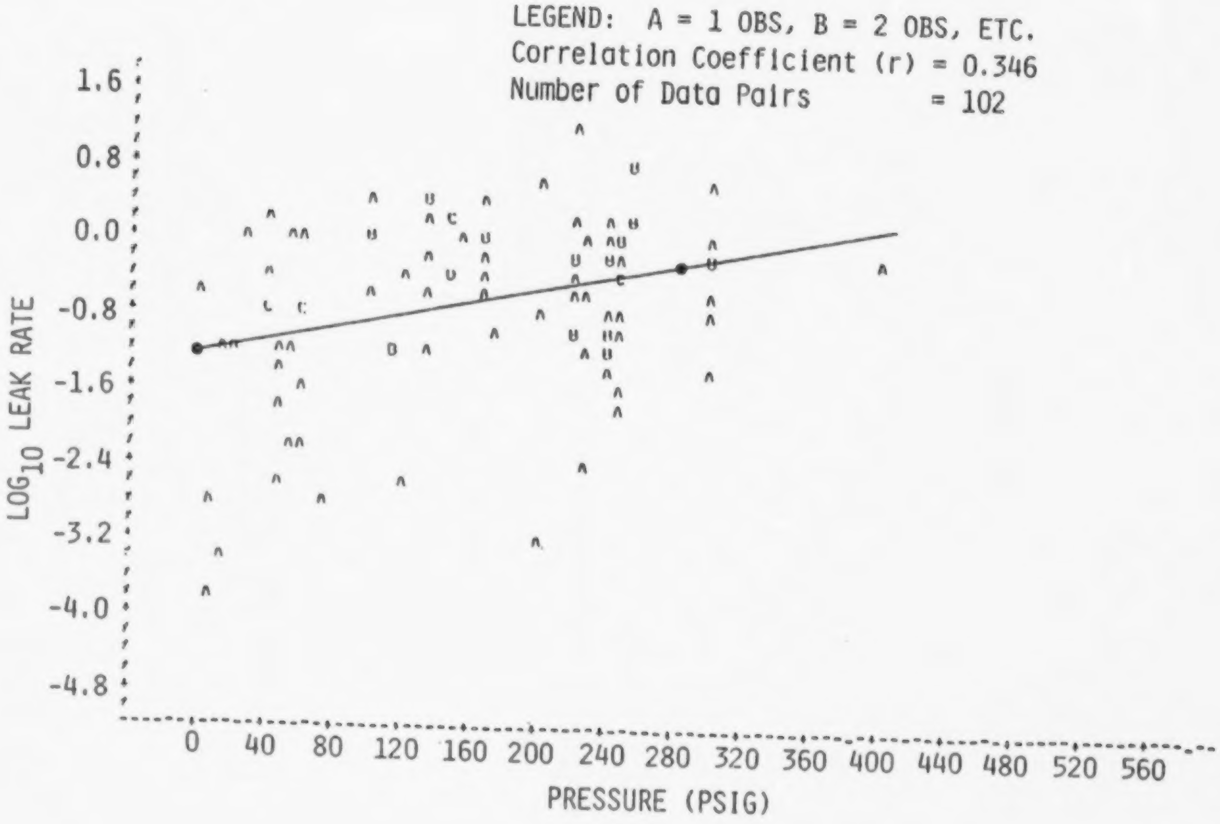


Figure 9. Leak Rate vs. Pressure - Compressor Seals, Hydrocarbon Service

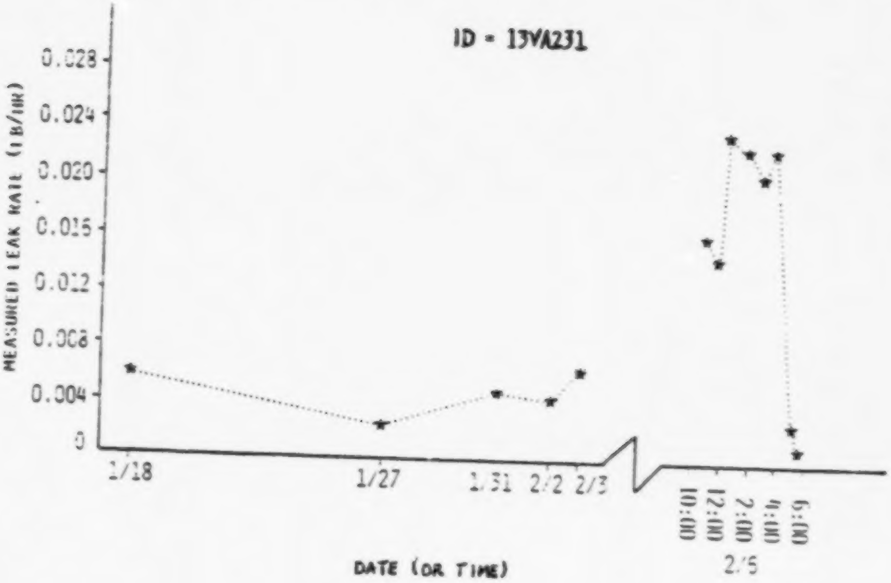


Figure 10. Short-Term Variation in Leak Rate - Valves

per hour varied by an order of magnitude over a period of approximately two hours. Such occurrences were not uncommon.

Part 2: Fugitive Emission Testing in SOCMI Process Units

The second part of this paper deals with current work in various SOCMI process units. This work is being supported again by EPA, IERL both in RTP and in Cincinnati and is being closely coordinated with OAQPS. There are essentially two programs being conducted simultaneously and in some cases in the same production unit. One of the programs is a fugitive emission screening survey which will be further described here.

The second is a program to determine the long and short term effects of maintenance on valves and the occurrence and reoccurrence of fugitive leaks from valves and pumps. This program will be more fully described in a paper to be presented by Weber and Smith at the APCA Meeting in Montreal later this year. This program will also develop correlations between screening values and leak rates for valves and pump seals in chemical process units.

The screening program being supported by IERL-RTP will screen all potential fugitive emission sources in some 20 process units except that only 5 to 15 percent of the flanges will be included. The work is being conducted by four companies: Radian, PEDCo, Acurex, and TRW. The last three contractors are forwarding their data to Radian for processing and interpretation, and Radian has the responsibility for the final report. In this study we are examining a wide variety of chemicals and attempting to study at least two process units for each type of chemical. Currently, screening has been conducted at ethylene, ethylene dichloride, vinyl acetate, vinyl chloride monomer, methylethyl ketone, phenol/acetone, and formaldehyde units. These data are not yet sufficiently reduced to give any estimate of the frequency or of variations between process units producing the same type of chemical.

In addition, this program is developing response factors for two types of hydrocarbon sniffers for a large number of industrial synthetic organic chemicals. This effort consists of a laboratory study where the response of specific gases is examined using two Century OVA and two Bacharach TLV hydrocarbon detectors. The response versus concentration data are being developed at several points between 100 and 10,000 ppm. It is the intent of this study to determine the utility of various types of hydrocarbon sniffers/portable hydrocarbon monitors in screening for maintenance or regulatory purposes for the wide variety of synthetic/organic chemical manufacturing processes. Once again the response factor data are not complete. It is, however, safe to say from a preliminary look at the results that response factor does vary with concentration and may vary between chemicals by one or more orders of magnitude.

This study was scheduled for completion in the summer of 1980 but has, however, suffered severe delays due to difficulties in accessing the various process units. This was caused by the recent chemical workers strike and by some reluctance on the part of plant managers to have the screening teams in their units. Currently, 12 units have been screened and the remainder of the screening visits have been scheduled. We anticipate that the data from this program will be ready in the Fall of 1980.

Acknowledgments

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EVALUATION OF FUGITIVE EMISSIONS AT A LARGE WOOD-PRODUCTS PLANT

by

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ABSTRACT

Under sponsorship of the U.S. Environmental Protection Agency (EPA), this program assessed fugitive particulate emissions at a large particleboard plant. Major and minor sources of fugitive particulate emissions were identified in a pretest survey. Emissions from major fugitive sources — open doorways in large material handling buildings — were directly sampled during a 2-week field program. Concurrently, ambient TSP data were collected daily at four sites outside plant boundaries using 24-hour continuous hi-vols and also wind-actuated units in an upwind/downwind arrangement. This paper presents the results of the sampling program and identifies control options applicable to the fugitive emissions.

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DISCLAIMER

This paper was prepared for the Fourth Symposium on Fugitive Emissions in New Orleans on 28 May 1980. The paper is based on the Final Report furnished to EPA by GCA Corporation, GCA/Technology Division, Bedford, Massachusetts 01730, in fulfillment of Contract No. 68-01-4143, Technical Service Area 1, Task No. 34. The opinions, findings, and conclusions expressed are those of the author and not necessarily those of EPA or of cooperating agencies. Mention of company or product names is not to be considered as an endorsement by EPA.

PROJECT BACKGROUND AND SCOPE

This project assessed the magnitude of fugitive particulate emissions at a large Northwest particleboard plant. Although the plant had taken a number of steps towards reducing fugitive emissions, violations of ambient air standards were still recorded at the local TSP monitoring station. Previous work indicated the plant was the primary industrial source responsible for these violations, based on correlations between wind patterns and measured TSP levels. Consequently, the Oregon Operations Office of EPA Region X requested GCA to assess the magnitude of fugitive emissions originating from the plant.

A 2-week sampling program directly measured particulate emissions from major fugitive sources. These data provided a range of emission rates for a variety of plant operational and ambient wind conditions. Ambient air quality was monitored for TSP at four sites outside plant boundaries by upwind/downwind sampling with source-oriented hi-vols. This arrangement was designed to provide an indication of the plant's contribution to ambient TSP levels.

Observation of daily plant operations enabled the identification of minor sources of fugitive emissions such as conveyor spillage, leaky ductwork and wind entrainment of spilled material. These observations coupled with a review of control technology generated a preliminary assessment of methods for reducing fugitive emissions.

DESCRIPTION OF FUGITIVE EMISSION SOURCES

Particleboard is manufactured by mixing prepared raw wood fibers with organic resin binders and heating the mixture under pressure to form hard solid sheets which are then trimmed and sanded to size and shape for sale and use. The plant facilities consist of a major building complex housing the three production lines and the storage and loading areas, and a number of smaller buildings housing raw material storage and preparation operations.

Fugitive particulate emissions originate primarily from handling, transport and storage of raw materials, which consist of green and dry planer shavings and plywood trim. Sources of fugitive emissions which leave plant boundaries can be summarized as:

- Major Sources — Material handling within four large buildings — the truck dump, dry shavings storage and two plywood trim storage buildings - and one open storage pile (which will soon be enclosed).
- Minor Sources - Small leaks in the air transport system, an occasional leak in a cyclone, conveyor belt losses, an occasional process equipment upset in the mill and flake area.
- Wind entrainment of particulate matter which originates from the above sources and accumulates over the entire plant.

MAJOR FUGITIVE PARTICULATE SOURCES — OPEN DOORWAYS IN MATERAL HANDLING BUILDINGS

Figure 1 shows the major fugitive emission sources which were sampled in this study. Each source is described below.

Raw materials — dry and green planer shavings and plywood trim material — are received from local sawmills in tractor-trailer trucks which are emptied into two large hoppers within the truck dumper building. A large hydraulic lift raises the entire truck at an angle, emptying it through a rear (truck) door. When prevailing winds are from the west, south or southeast, dust generated from the dumping operation is carried out the northeast facing doorway. A vibrator located on one of the dumpers to loosen compacted shavings somewhat increases dust generation. Green shavings (40 to 60 weight percent moisture) generate substantially less dust than dry shavings (10 to 11 percent moisture) or plywood trim. Under normal operation, about 9 to 10 trucks per hour are dumped.

From truck dump hoppers, material travels to storage silos by two belt conveyor systems, also shown in Figure 1. When silos are full, incoming material is diverted to storage. Green shavings enter a large outdoor storage pile. Dry shavings enter conveyors located underneath the dry storage building roof and fall to storage piles within the building. Plywood trim is similarly deposited into one of the two ply trim storage buildings by overhead conveyors.

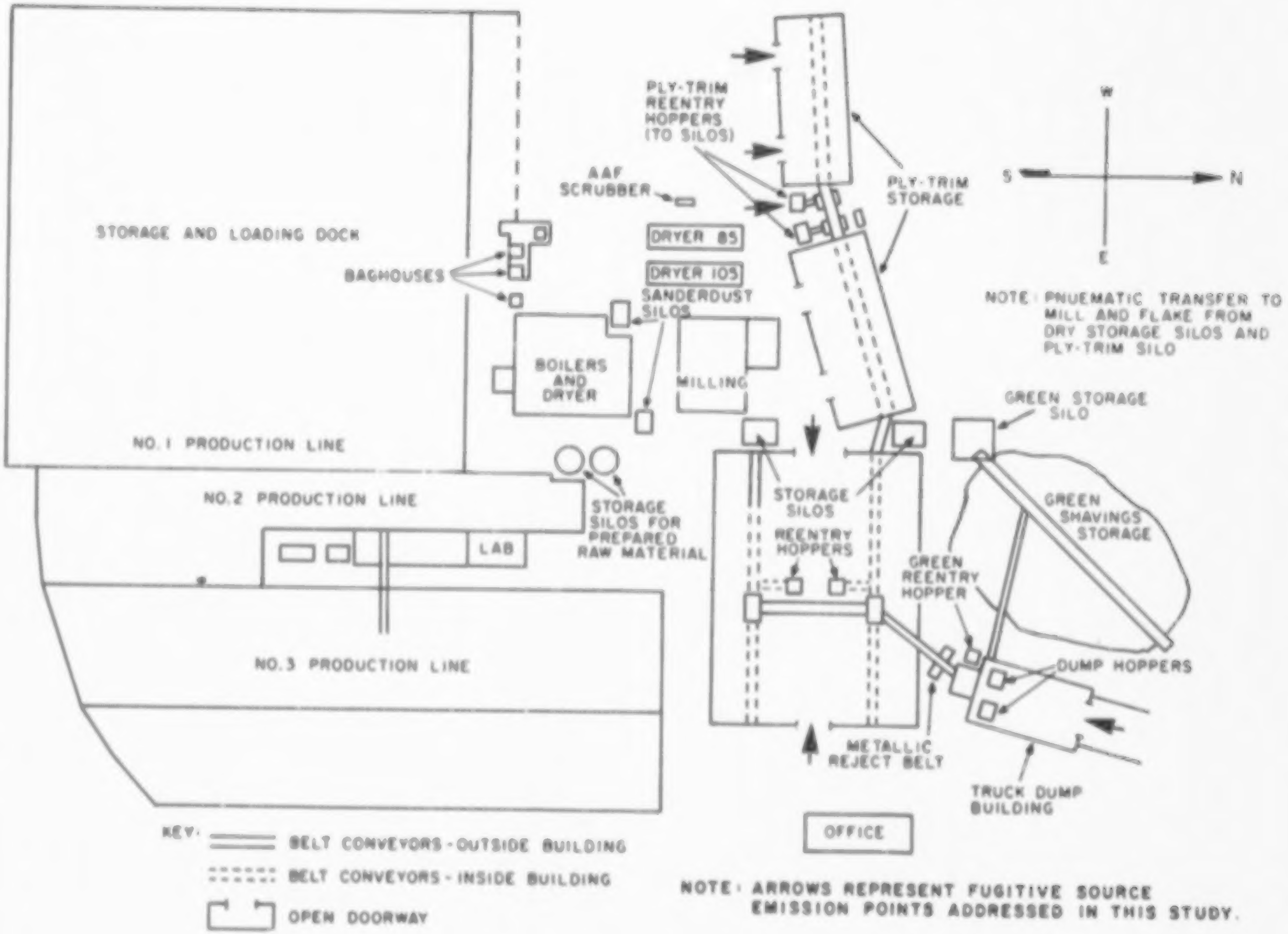
When incoming trucks cannot maintain necessary levels in the storage silos, silos are refilled with material previously placed in storage. Bucket loaders "scoop" raw material from storage areas to reentry hoppers and material travels to appropriate silos by the main belt conveyor system shown in Figure 1.

In summary, fugitive emissions from the three material storage/handling buildings exit to the atmosphere through large open doorways. The doorway emissions are generated by the following processes:

- Discharge of raw material to storage piles from overhead conveyors.
- Bucket-loader scooping of stored material and dumping to conveyor hoppers.
- Wind reentrainment of particulate during periods of no internal building activity, which only occurs with high winds.

MINOR FUGITIVE PARTICULATE EMISSION SOURCES

In addition to the major fugitive sources, i.e., the open doorways, a number of minor sources were also identified. External conveyors, although covered on three sides, lose some material. Air systems also used to transfer raw material occasionally leak to some degree. An occasional upset in the mill and flake area generates some fugitive emissions. All of these minor sources discharge some particulate directly to the ambient air, and also create accumulations of dust which are then reentrained by winds. The upwind/downwind sampling program addressed the ambient air impacts of these (and all other) plant emissions.


STORAGE AND LOADING DOCK
BAGHOUSES
NO. 1 PRODUCTION LINE
NO.2 PRODUCTION LINE
LAB
NO.3 PRODUCTION LINE
AAF SCRUBBER
DRYER 85
DRYER 105
SANDERDUST SILOS
BOILERS AND DRYER
MILLING
STORAGE SILOS FOR PREPARED RAW MATERIAL
PLY-TRIM REENTRY HOPPERS (TO SILOS)
PLY-TRIM STORAGE
STORAGE SILOS
REENTRY HOPPERS
GREEN REENTRY HOPPER
METALLIC REJECT BELT
OFFICE
GREEN STORAGE SILO
GREEN SHAVINGS STORAGE
DUMP HOPPERS
TRUCK DUMP BUILDING
W
S
N
E
KEY:
BELT CONVEYORS - OUTSIDE BUILDING
BELT CONVEYORS - INSIDE BUILDING
OPEN DOORWAY

NOTE: PNUEMATIC TRANSFER TO MILL AND FLAKE FROM DRY STORAGE SILOS AND PLY-TRIM SILO

NOTE: ARROWS REPRESENT FUGITIVE SOURCE EMISSION POINTS ADDRESSED IN THIS STUDY.

Figure 1. Major Fugitive Emission Sources.

HISTORY OF FUGITIVE EMISSION CONTROL AT THE PLANT

Handling of raw materials by bucket loaders, conveyors and active storage piles is inherently a very dusty operation. When the plant was designed and constructed in 1960, little attention was given to control of these fugitive dusts. All raw material was stored outdoors in piles or open-sided sheds, belt conveyors were exposed to prevailing winds, plant grounds were unpaved and the truck dumpers were unenclosed. Since this time, the plant has made a number of operational improvements which have served to significantly reduce the potential for fugitive emissions. These are summarized in Table 1.

TABLE 1. SUMMARY OF MAJOR CONSTRUCTION ACTIVITY AT DURAFLAKE WHICH REDUCED FUGITIVE EMISSIONS

Year	Activity
1969	Constructed truck dump building over the two dumpers. Purchased used street sweeper. Paved parking lot and eastern plant grounds. Closed off east end of dry storage building with partition.
1970	Covered roof area between dry hemlock and fir storage sheds. Installed truck dump negative air exhaust system and found only partially effective.
1972	Enclosed conveyor belts on dry shavings roof. Enclosed flight conveyors to dry storage silos.
1973	Paved western plant areas. Installed roof over plywood trim storage buildings.
1974	Purchased vacuum truck for cleaning silos and spilled material.
1976	Installed canvas curtain below green shuttle in conveyor discharge to reduce wind entrainment. Corrected belt conveyor spillage problems in mill and flake areas.
1977	Installed self-closing personnel doors on dry storage and truck dump buildings. Installed door to close off eastern opening of the dry storage building.
1978	Installed fire hose connections to allow hosing of dusts accumulated on roofs of dry and ply trim storage buildings, and mill and flake areas. Began construction of green shavings pile enclosure building. Ordered new street sweeper.

DESIGN AND OPERATION OF SOURCE SAMPLING TRAINS

Fugitive emissions from the open doorways were directly measured by traversing the plume exiting each doorway with a specially designed sampling train consisting of a calibrated hi-vol motor with filter, and a cyclone pre-separator to provide a 10 µm particle size cut. Each doorway was uniformly traversed in a rectangular grid pattern to obtain an average concentration of exiting particulates during the hour-long sampling run. The exit velocity of the particulate plume was monitored and recorded at each traverse point. With these data, mass emission rates could be calculated based on the average particulate concentration, the average exit velocity and the doorway cross-sectional area.

Each sampling train consisted of an inlet nozzle, a cyclone preseparator, a standard 8 x 10 inch hi-vol filter, a hi-vol blower motor, and auxiliaries as shown in Figure 2. Sampling flow rate was controlled by a variac (rheostat) and monitored by a dial gauge on the blower exhaust and also a manometer across the cyclone. The 4-inch diameter inlet nozzle was designed to provide sampling at a rate approximately equal to typical doorway exit velocities so sampling would approach isokinetic conditions. The train was calibrated by techniques similar to those used for hi-vol ambient air samplers, both before and after the sampling program. Design of the train allowed for easy component disassembly to facilitate sample recovery from cyclones and connecting piping by acetone washing.

For each source sampling run, the train was suspended in front of a particular doorway from a trolley assembly similar to monorails used for stack sampling. A pulley and rope arrangement allowed manual positioning of the train at each traverse (sampling) point. Monorails were installed in a semipermanent fashion above two doorways (the truck dump and western door of dry storage) while remaining doorways were served by a portable design which could be leaned against the doorway. The inlet nozzle was always located about 12 inches just outside each doorway, to ensure measurement of actual atmospheric emissions, not internal building concentrations.

On a few occasions when winds were light and/or variable, the doorway exit flow reversed for brief periods such that no emission occurred. In these instances, sampling was temporarily halted by stopping the blower, and resumed when measurable flow was observed to exit the doorway. This procedure was necessary so sampling data would be compatible with the technique used to estimate annual emissions.

FUGITIVE SOURCE SAMPLING RESULTS AND EMISSION ESTIMATES

A total of twenty-seven 1-hour sampling runs characterized emissions from the four major sources under a variety of plant operational and wind conditions, as shown in Table 2. From an assessment of annual wind patterns and plant operation data, annual emission estimates were developed for each source as shown in Table 3. Since doorway emissions are nonexistent when winds blow into the doorway, the several years of wind data available for this site were used to estimate the amount of time emissions would blow out of the doorways.

On an annual basis, fugitive particulate emissions from the four material handling buildings are estimated at about 50 tons or 15 percent of process stack emissions. However, GCA feels the sampling data are biased low due to the wet weather and light winds encountered during the study. The source sampling found that peak emission rates from these buildings could easily amount to 40 lb/hr or more on weekends or nights with moderately southwesterly and westerly winds, compared to process stack emissions of 100 lb/hr.

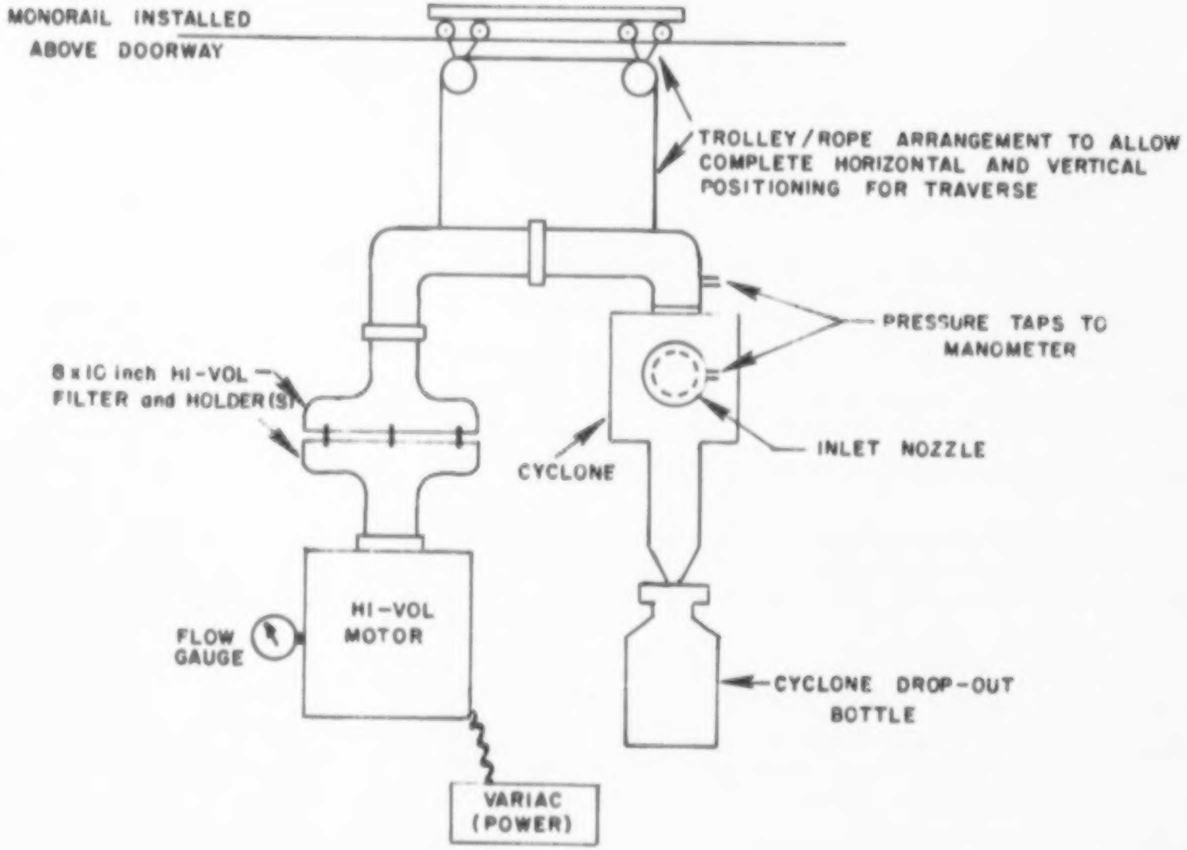

MONORAIL INSTALLED
ABOVE DOORWAY
TROLLEY/ROPE ARRANGEMENT TO ALLOW COMPLETE HORIZONTAL AND VERTICAL POSITIONING FOR TRAVERSE
PRESSURE TAPS TO MANOMETER
8 x 10 inch HI-VOL FILTER and HOLDER(S)
INLET NOZZLE
CYCLONE
HI-VOL MOTOR
FLOW GAUGE
CYCLONE DROP-OUT BOTTLE
VARIAC (POWER)

Figure 2. Front view of source sampler constructed for Duraflake sampling program.

TABLE 2. SUMMARY OF SOURCE SAMPLING DATA FOR MAJOR FUGITIVE SOURCES

Source	Number of samples	Average emissions lb/hr <10μ	Average emissions lb/hr >10μ	Internal activity
Truck dump	5	0.3	3.7	Normal operation, light winds
	1	0.9	12.0	One truck, very dusty material, light wind
Dry storage building west door	2	0.1	1.9	No activity; front door closed, light wind
	2	0.1	4.7	Light activity; front door open, light wind
	1	0.8	13.0	Continuous conveyor discharge, front door open, light wind
Dry storage building east door	5	0.5	12.0	Normal weekend payloader operation, light to moderate wind
	1	1.0	37.0	Heavy payloader operation near door; moderate winds
Ply trim building*	4	0.1	7.0	Peak emissions during conveyor discharge, light winds
	1	0.3	25.0	One dusty conveyor discharge, moderate winds
	1	0.2	8.1	Average emission during payloader removal of stored material
Ply trim hopper	4	0.1	8.7	Dust from payloader discharge to reentry hopper, time averaged emission
Roof monitors[†] production line 3	13	0.1		Survey measurements of roof monitor emissions during normal operation

*Reported values for one of two doors in building emissions normally escaped only through one door.

[†] Data for particles less than about 25 μm.

TABLE 3. ANNUAL EMISSION RATES FOR MAJOR FUGITIVE SOURCES

Source	Estimated annual operating hours	Percent of year with dust generating wind	Average TSP emission (lb/hr)	Net annual emission (tons/yr)
Truck dump	2,850	51	3.7	2.7
Dry storage-west door				
normal daily activity	6,260	54	1.9	3.2
payloader operation	4,000	54	12.0	13.0
Dry storage-east door				
normal daily activity	313	46	1.9	0.14
payloader operation	4,000	46	12.0	11.0
Ply trim buildings				
conveyor discharge	830	53	7.1	1.6
payloader activity	4,000	75	8.1	12.0
Reentry hopper at ply trim	4,000	53	8.7	9.3
TOTAL ANNUAL DOORWAY EMISSIONS				53
Inventoried process (stack emissions)	8,100	100	96.2	391

Particle size data collected during all sample runs showed that less than 5 weight percent of emissions were smaller than 10 μm aerodynamic diameter. However, this does not necessarily indicate that most particles are heavy and soon settle to the ground. Observations during sampling found most emitted particles were entrained in prevailing winds and significant fallout on plant grounds did not occur.

UPWIND/DOWNWIND AMBIENT SAMPLING APPROACH

To evaluate the impact of particulate emissions from the plant on ambient air quality, upwind/downwind sampling was conducted concurrently with the source sampling programs. Based on an analysis of historical wind data, four ambient sampling sites were selected, two upwind and two downwind of the plant.

To the north, one hi-vol operated continuously for 24-hour periods while a colocated, wind-actuated hi-vol only operated when winds were from the plant sector. An additional single hi-vol, also located to the north, operated continuously for 24-hour periods.

A similar arrangement of hi-vols was operated to the south of the plant. Since winds tended to blow north-south, or south-north, these hi-vol stations were designed to cope with anticipated wind patterns.

Hi-vols operated daily for 12 days with filter changes conducted at midnight of each day. An electric clock wired into the wind controls recorded the actual time the wind-actuated hi-vols operated. Wind direction and wind speed were continuously monitored and recorded on a strip chart unit.

AMBIENT TSP MONITORING RESULTS

The ambient monitoring program collected a total of forty 24-hour TSP samples at six hi-vols to the north and south of the plant for 12 continuous days. The ambient data for each site is summarized in Table 4.

Upwind/downwind sampling showed substantial increase in ambient TSP when winds originated from a sector including the plant boundaries, but excluding adjacent industrial facilities. Based on data from this monitoring program, particulate emissions from the plant apparently increased ambient TSP roughly two to four times above measured background levels, as shown in Table 5.

Weather conditions during the sampling program did not appear representative of those which would produce maximum fugitive emissions from the plant. Steady rainfall was experienced over roughly one-half of the period and winds were generally calm or light. Further, TSP measured by GCA at the permanent site to the north was significantly lower than that recorded by the state agency over past years. For these reasons, TSP levels measured at ambient sites and also from fugitive (doorway) sources at the plant are considered to represent a lower limit to emission potential, not a maximum.

CONTROL TECHNOLOGY ASSESSMENT

In general, control options for fugitive particulate emissions fell into two categories:

- Complete control by capital-intensive techniques; i.e., evacuating all buildings to baghouses, and redesigning raw material handling processes.
- A lesser degree of control, achieved by minor structural modifications, operational changes, and a dramatic increase in attention to plant housekeeping and cleanliness.

Options for control of each type of fugitive emission are summarized in Table 6 and discussed briefly below.

Complete control of the open doorways can only be accomplished by evacuation and diversion of the emission flow to a baghouse. The buildings cannot be sealed because of the potential for explosions and also worker safety/health concerns. Although technically feasible (the metallurgical industry often uses complete building evacuation to control plants containing a number of diffuse emission sources), the capital costs per building would be on the order of one-half million dollars. This cost for complete control must be weighed against the potential emission reduction. Fugitive emissions from these buildings account for an estimated 15 percent of process stack emissions on an annual basis and a maximum of 40 percent of stack emissions on a peak daily basis.

As an alternative to the baghouse option, emissions from these buildings could be reduced, possibly by as much as 50 percent, by implementing a number of structural and operational modifications listed in Table 6; i.e., reducing doorway size, constructing enclosure type sheds over reentry hoppers, installing conveyor discharge downspouts, and retraining plant operators.

TABLE 4. SUMMARY OF AMBIENT TSP SAMPLING CONDUCTED IN SEPTEMBER 1978, $\mu g/m^3$

Date	satellite	Mortuary 24-hour	Mortuary W. D.	South Main 24-hour	South Main W. D.	South satellite	Wind and weather
9/7 - THU	28	-	-	38	-	-	Light south wind, clear until noon, rain until 6 a.m.
9/8 - FRI	77	99	216	46	-	-	Light south wind, rain all day
9/9 - SAT	70	95	233	25	-	70	Light south wind, rain
9/10 - SUN	137	162	269	45	160	-	Light south-se wind, rain in mornings, clear thereafter
9/11 - MON	179	91	207	61	-	37	Light south wind, dry by evening
9/12 - TUE	99	41	-	86	152	-	Light northerly winds, variable
9/13 - WED	73	58	100	57	73	40	Light variable wind, no rain
9/14 - THU	65	32	60	44	63	-	Light variable wind, no rain
9/15 - FRI	122	43	180 (1-hour)	137	161	78	Light north wind, dry
9/16 - SAT	69	31	-	143	192	-	Light north wind, dry
9/17 - SUN	58	48	175	91	80	-	Moderate south wind, dry - a.m., rain - p.m.
9/18 - MON	120	73	302	66	116	57	Light south wind, dry
Mean	91	70	194	70	192	56	
Maximum	179	162	269	143	125	78	

TABLE 5. AVERAGE MEASURED TSP BY WIND DIRECTION, $\mu g/m^3$

	North satellite	North Main 24-hour	North wind directional	South Main 24-hour	South wind directional	South satellite
Average of 7 days with south wind	95	96	200	53	-	55
Average of 3 days with north wind	97	38	-	122	168	-

Note: Winds not always constant in direction.

TABLE 6. SUMMARY OF CONTROL OPTIONS APPLICABLE TO DURAFLAKE

Emission source	Control option	Comments
Major sources - open doorways	Evacuation to baghouse	Capital intensive Very efficient
	Structural modification - doorway size reduction to reduce emission flow rate - enclosure sheds over reentry hoppers to minimize dust entrainment - conveyor downspouts to minimize free fall distance	Relatively inexpensive Less effective than baghouse
	Operational changes - retraining of bucket loader operators to operate equipment more carefully - more diligent closure of existing doors	
Minor sources	Complete enclosure of belt conveyors	Requires cleaning
	Installing more effective belt wipers	
	More effective control of leaky ductwork, cyclones, etc.	
General dust accumulation	Vacuum sweeper - daily use	New sweeper ordered
	Hosing of roofs and ductwork - daily	Hose connections currently installed
	More careful operation of vacuum truck	
	General reduction in dust generating activity	

Improved control of minor point-type sources of fugitive emissions can be achieved primarily by more effective conveyor belt enclosures to eliminate spillage, use of more effective belt wipers, and more attention to repair of leaky duct work, cyclones, and other minor sources.

A major problem at the plant is the substantial accumulation of dust over plant surfaces, which contributes to windblown fugitive emissions. The solution here is simply more attention to housekeeping details. A three-wheel, brush-type street sweeper is reportedly on order and should be used daily on all plant grounds. Hosing of rooftops and other plant surfaces that collect dust should be conducted daily since GCA's observations indicated enough material can accumulate in 1 day to constitute a windblown dust problem. The plant currently operates a vacuum truck for cleaning major spills and/or storage silos and hoppers, and more frequent use of this equipment should be encouraged.

CONCLUSIONS AND RECOMMENDATIONS

Based on GCA's evaluation of fugitive emissions during the 2-week sampling program, the following comments and recommendations are offered.

- Major fugitive emission sources contribute about 50 tons per year of TSP annually, or about 15 percent of inventoried stack TSP.
- Violations of ambient TSP standards were recorded outside of plant property.
- Upwind/downwind hi-vol sampling showed increased ambient TSP when winds were from the plant sector.
- Based on the 2 weeks of hi-vol data, all plant emissions increase ambient TSP by a factor of 2 to 4 above background levels.
- All sampling data are considered to represent minimum emission levels since the sampling period experienced low wind speeds and wet weather.
- State-of-the-art control of fugitives involves capital-intensive measures — complete building evacuation and/or process redesign.
- A moderate level of control can be achieved by minor structural modification and minor operational change.
- A dramatic increase in overall housekeeping is essential to reduce windblow fugitive dusts.
- Although only 5 percent of the fugitive emission particulate was measured at less than 10 μm, visual observations indicated that much of the TSP became entrained in ambient wind currents and did not descend on plant grounds.

A Method for Measuring Fugitive Emissions From Cast House Operations

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Betz•Converse•Murdoch•Inc.

Abstract

An attempt to measure fugitive emissions from blast furnace cast house operations presented a variety of problems. A method was developed to determine a mass emission rate. The method utilizes high volume samplers placed in a multipoint array where temperature and velocity measurements also are made. The reasoning behind the method is discussed, and the method is compared to other "state of the art" procedures for measuring fugitive emissions. Certain factors which affect the emission measurements are discussed. Results indicate that the method is reasonably accurate for determining mass emission rates from cast house operations.

This paper is a synopsis of several measurement programs and, although the basic methodology was the same, the type of equipment used varied for each program. The method, currently being used in an ongoing program to quantify emissions from cast houses, is continually undergoing refinement.

The emissions generated by a blast furnace during casting originate from relatively small point, line and area sources (tap hole, runners, hot metal cars); they expand quickly to the dimensions of the cast house and exit by a number of routes. Emissions from the tap hole are caused by the cooling of the hot metal as it exits the furnace and encounters the atmosphere. More emissions are created by a violent cast with a lot of hot metal turbulence than are generated by a smooth, controlled cast. Oxygen lancing of the tap hole at the beginning of a cast and the enlargement of the tap hole by erosion during casting also contribute to increased emissions.

The generation of emissions from the iron runners, iron trough and slag runners is apparently a function of the surface area of metal exposed to the atmosphere and the metal temperature. As the metal cools, carbon emerges from the hot metal solution as "kish", a form of graphitic carbon that is light, flaky and readily air-borne. The trough and runners are lined with clay and coke breeze which must be thoroughly dry prior to casting. Any residual moisture reacts violently with the molten metal, resulting in greater emissions.

The hot metal cast from a blast furnace is transported to further processing facilities via hot metal cars (i.e., ladle cars, torpedo cars). The hot metal cars are filled by the iron runner spouts. If the hot metal cars are too cool, if a "skull" has formed over the car opening, or if the hot metal splashes onto the inside of the car opening, the hot metal cools very rapidly, and the emissions from the cars can become extremely dense.

Because fugitive emissions are not confined, they are inherently difficult to quantify. Three basic strategies[1,2,3] have been developed for the measurement of fugitive emissions: the roof monitor, the quasi-stack, and the upwind-downwind methods. All three methods, or variations thereof, have been used in an attempt to quantify blast furnace cast house emissions[4,5].

The roof monitor measurement technique assesses emissions exiting through monitors, doors, windows, ventilators or other openings. Usually high volume samplers[6] are utilized to measure the concentration of particulate passing through the opening. A velocity is determined and a mass emission rate is calculated for each opening. The numerous openings present in cast houses, and the physical problems associated with sampling at those openings, precludes the use of the roof monitor sampling method.

The quasi-stack sampling method employs a temporary hood which is exhausted by a fan to a temporary stack. The hood and exhaust system are designed to capture most (theoretically all) of the emissions from the process being investigated. Then, the mass emission rate is measured by standard stack sampling techniques. The quasi-stack sampling method is impractical for cast house testing because it interferes with production equipment and personnel. Also, the design for the temporary hoods would have to meet strict criteria, including the ability to withstand high temperatures.

The third method, upwind-downwind sampling, as well as a fourth method, measurement in the plume, seemed the most promising methods to use. The plume measurement method was developed by Jacko[7] for measuring coke oven pushing operations. The method used a high volume sampling device suspended from a boom into the plume. The boom also held velocity and temperature measuring instruments. The push was filmed with a 16 mm movie camera. The resulting film was then projected onto a screen and measurements were made to determine the cross sectional area of the plume. The film was also used to determine when the samplers actually intercepted the plume so that an accurate sampling time could be determined.

Observations of a number of casts indicated that neither the plume measurement technique nor the upwind-downwind method would work. The numerous points of exit for emissions from a cast house result in a plume whose boundaries are not as well defined as those from a coke oven, making it difficult to determine the plume cross-sectional area. Also, interferences from surrounding sources would have had a substantial impact on either sampling method.

The sampling methodology that eventually evolved was one that had been dismissed earlier as being too difficult to implement. The method could be described as an in-situ stack method because the entire cast house was considered to be the stack. The cross-sectional area of the cast house was divided into sub-areas and each sub-area was sampled simultaneously. Samples were taken with standard high volume samplers with constant flow controllers. The samplers were placed on a scaffolding which was erected on the roof girders just above the crane.

The philosophy behind such a sampling arrangement was simple. Observations indicated that emissions exited the cast house via five routes: hot metal car (ground) level; cast house floor doors; windows; roof monitor; and around the furnace shell at roof level. The emissions from each route were present in varying degrees during each cast, but the bulk of the emissions appeared to be exiting via the higher exit points (windows, monitor, roof top). By sampling at the roof girder level, (approximately window height), the bulk of the emissions would be intercepted.

One objective of the first test program was to determine emission factors for each source within the cast house (i.e., tap hole, runners, hot metal cars). Consequently, the scaffolding and samplers were placed to maximize plume interception from the individual sources while maintaining sufficient coverage of the entire cast house. The spatial limitations of the cast house girder system determined the exact placement of the scaffolding.

To develop emission rates, plume velocity and cross-sectional area must be determined. Conduction and convection transfer significant quantities of heat to the surrounding air creating a thermal draft which causes a rising air current. As the heated air stream rises from a hot surface, it mixes turbulently with the surrounding air. The higher the air column rises the larger and more diluted with ambient air it becomes.

Equations have been developed that describe the diameter of a hot rising jet at any height above a hypothetical point source located a distance, z, below the actual hot surface.[8] The rising air column expands approximately according to equations 1 and 2 as indicated in Figure 1. A cross-sectional area at the height of the samplers was calculated from equations 1 and 2 for each of the hot sources in question (iron trough, runners, hot metal cars). The resulting areas are indicated in Figure 2 by the shaded areas.

To complete the flow calculations, a velocity must be determined and applied to the previously computed areas. The velocities of the emissions were primarily determined by photogrammetric methods. A movie camera with a precisely controlled shutter speed was used to photograph various portions of each cast. The developed film was projected onto a grid. As the film was advanced a single frame at a time, an identifiable portion of a particular plume was followed on the grid. By using simple geometry, the grid was calibrated to the known size of objects projected onto the grid and distances between reference points were established. The velocity of the plume was calculated by counting the number of frames it took the plume to travel the distance between reference points and multiplying by the framing speed of the camera. This procedure was followed a number of times for each plume to arrive at an average plume velocity. For emission points, such as over the iron runners, which did not have readily identifiable plume attributes, a different procedure was used. Neutrally bouyant helium filled balloons were released and tracked as they were projected onto the grid as described above. The vertical transport of the balloons was timed for comparison with the calculated velocities. In addition, a hot wire anemometer was used to determine velocities outside the areas of the plumes.

$$z = 2D_s^{1.138} \qquad (1)$$

$$D_c = 0.5\ (z+Y)^{0.88} \qquad (2)$$

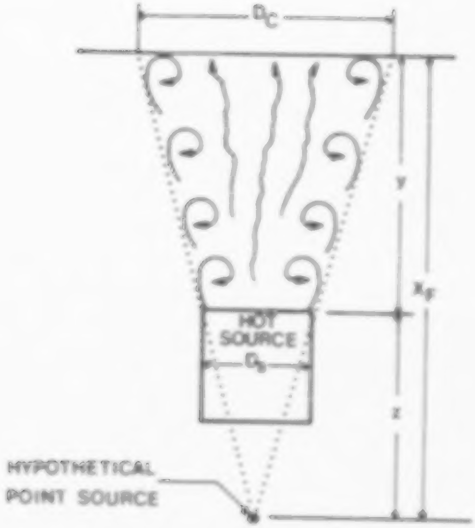
where:

D_c = the diameter of the hot column of air at the level in question, ft

D_s = the diameter of the hot source, ft

y = the distance from the hot source to the plane of D_c, ft

z = the distance from the hot source to the hypothetical point source, ft.



D_c
y
x_F
HOT SOURCE
D_s
z
HYPOTHETICAL POINT SOURCE

Figure 1

THEORETICAL EXPANSION OF AIR COLUMN
DUE TO HOT SOURCE

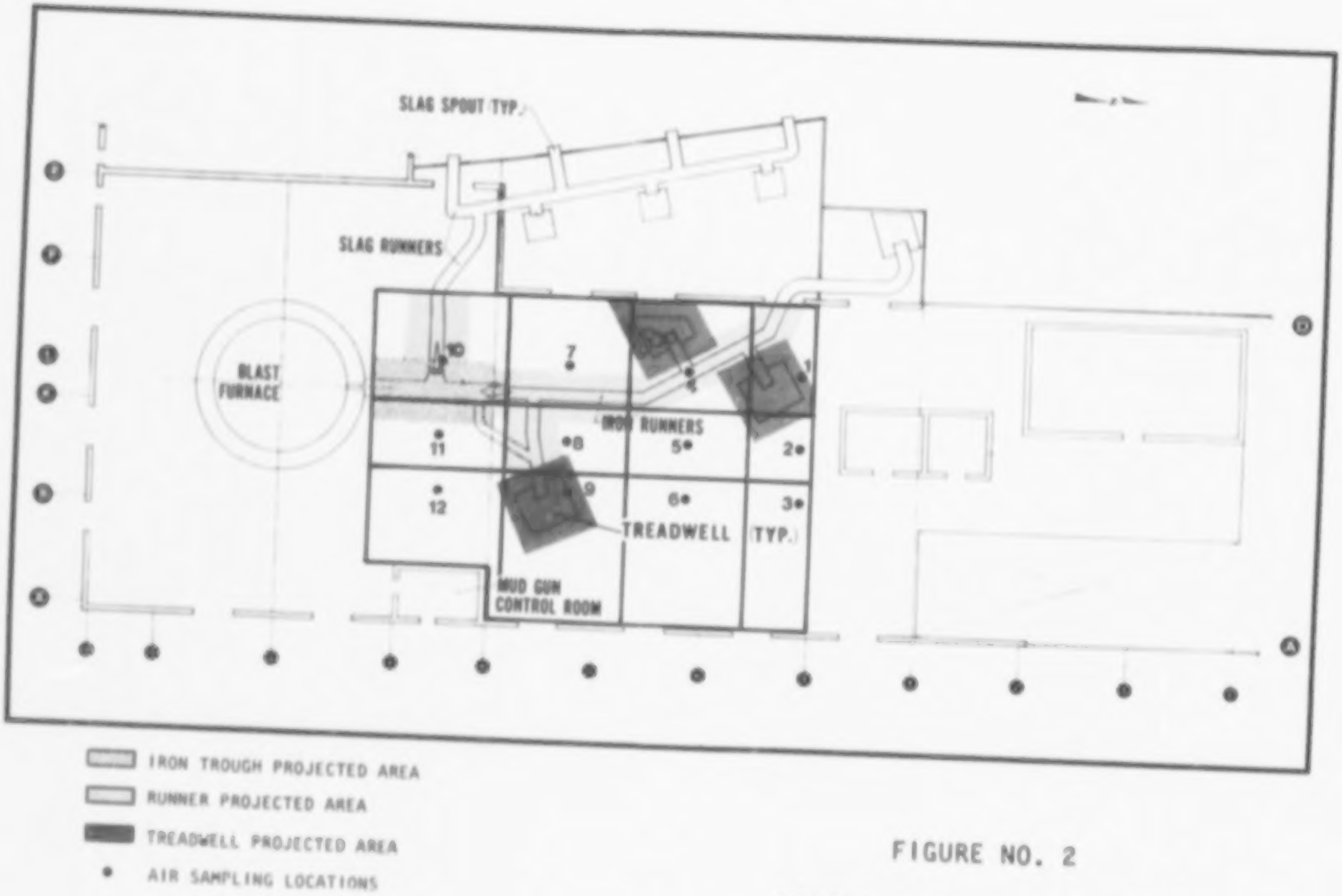

SLAG SPOUT TYP.
SLAG RUNNERS
BLAST FURNACE
IRON RUNNERS
TREADWELL (TYP.)
MUD GUN CONTROL ROOM
1
2
3
4
5
6
7
8
9
10
11
12
IRON TROUGH PROJECTED AREA
RUNNER PROJECTED AREA
TREADWELL PROJECTED AREA
AIR SAMPLING LOCATIONS

FIGURE NO. 2

SAMPLING NETWORK SCHEMATIC

Once velocities and areas were determined, the flows at a given sample location were calculated. The gas flow at a given sampler was calculated as a time weighted average of each of the velocities and sub-areas as calculated above. For example (referring to Figure 2), the determinations of flow within the"domain" of sample point number 5 is composed of the flow from the non-plume area, the flow from a portion of the runner when filled with hot metal, and the flow from a portion of the plume from hot metal car number 3 during the time that hot metal is going into that car. This relationship can be expressed mathematically as follows:

$$Q_a = \frac{\sum_{i=1}^{n} V_i A_i t_i}{T} \qquad (3)$$

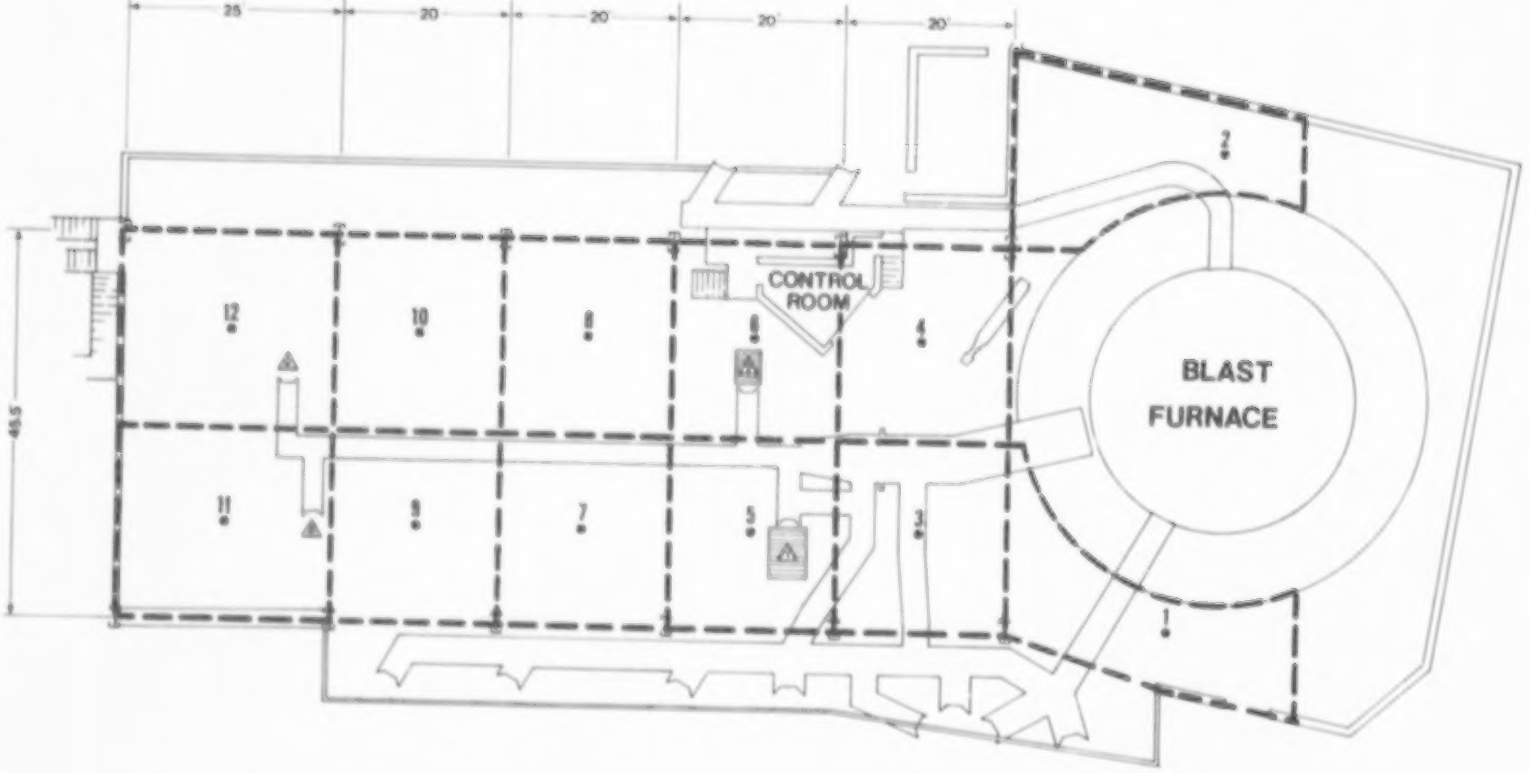
where:

A_i = the i^{th} area, ft^2
T = total time of test, min.
t_i = the time that the i^{th} area was affected by the i^{th} velocity, min.
Q_a = the average flow at the sample point (ventilating rate), ft^3/min
V_i = the i^{th} velocity, ft/min

Note: n is a variable depending upon the specific point.
$A_i = f(D_c)$

Twelve standard high volume samplers were placed on the scaffolding for the particulate measurement as indicated in Figure 2. All twelve samplers were activated simultaneously by a common switch at floor level. The samplers were started when tap hole drilling was started. Since there are significant emissions after the furnace is plugged, the samplers were not turned off until five minutes after the mud gun was placed in the tap hole. Then, the filters were changed and the samplers were readied for the next test.

During the first test program, the emissions were observed to have a pronounced horizontal movement toward the furnace which acted as a natural draft chimney. This unanticipated movement of the emissions prevented the determination of emission factors for each individual source and caused a reassessment of the sampler placement. In subsequent test programs, normal stack testing methodology has been adopted; i.e., an attempt has been made to sample equal areas with the samplers placed at the center of each area and to include the areas at the front of the cast house on either side of the furnace. An example of such an arrangement is shown in Figure 3. Final placement of the samplers is, however,



25'
20'
20'
20'
20'
45.5'
CONTROL ROOM
BLAST FURNACE
1
2
3
4
5
6
7
8
9
10
11
12

● AIR SAMPLING LOCATIONS
△ LOCATION OF HOT METAL POURING STATIONS

Figure 3

SAMPLING NETWORK SCHEMATIC

still dependent upon the spatial limitations of the cast house girder system.

One other major revision, the elimination of velocity determination by photogrammetry, has been made to the basic test method used in subsequent programs. Instead, hot wire anemometers and thermocouples were placed at each sampler location. The thermocouple signals were fed to a multipoint recorder. In an attempt to maximize data acquisition yet minimize cost, the hot wire anemometer outputs were fed to a multiplexer and then to single channel strip chart recorders. Velocities at four different sample locations were recorded simultaneously.

Standard high volume samplers were chosen primarily for their ease of operation. Additionally, the upright design prevented loss of sample, and the cover prevented sample contamination from fallout. The design also provided some size selectivity which excluded particles that would probably settle out within the cast house. The samplers were equipped with constant flow controllers which simplified data reduction and enhanced the data reliability.

Tests during each cast also included particle size data collection using a five stage cascade collection device attached to one of the high volume samplers. The cascade device was moved from sampler to sampler throughout the program. Because only one cascade device was used, no simultaneous particle size data was collected. Since it is unknown whether the particle size data variability was point-to-point variability or test-to-test variability, the data was treated as if it were from the same population. Averages indicate that approximately 85% of the particles are less than the 7.2 micron cut-off size of the first stage. Because the high volume sampler is fairly effective up to about 100 microns, the samples were probably indicative of the emissions actually leaving the cast house.

Testing was also conducted between casts so that background data could be obtained. The data collected for the periods between casts was considered as "upwind" data and was subtracted from the cast or "downwind" data in subsequent analyses. This data treatment was meant to account for the material remaining in the cast house after the cast was completed and the driving force (heat) was removed. The residence time of this suspended material could not be accounted for and the extent to which it contributed to the cast test results was unknown. Therefore, it was subtracted from them.

In one of the test programs, observed interference of particulate matter from an adjacent process necessitated the acquisition of the background data. Because the generation of the interfering particulate matter was not constant, the impact on the results of the individual cast tests is unknown, but it is believed that the average values were reliable estimates.

During normal casting operations, the slag which floats on top of the hot metal is skimmed off. It is shunted via runners to a slag pit adjacent to the cast house or into slag pots which then are transported to a remote disposal area. In some cast house operations, the cinder notch is opened and slag is flushed from the furnace without casting any hot metal. This flushing operation is performed just prior to a cast. Since this operation results in noticeable emissions, testing was performed during the flushes and the results were added to those obtained from cast tests.

One area of concern not addressed during any of the sampling programs was any effect on the measurements, caused by local meteorology. Since cast houses are fairly open, wind direction and velocity could modify pollutant trajectories. Also, the difference between summer and winter temperatures can cause variations in emissions. During one test program, what appeared to be a convection cell was established within the cast house itself. To what extent this cell would impact on the measurements is unknown as is its cause and relationship to the local meteorology.

Although some areas need further investigation and a few questions need to be answered, the preliminary results of the in-situ stack method are encouraging. To date, the method has been used to generate mass emission rate data for a process for which little reliable data previously existed. The method uses reliable, readily available equipment and is suitable in a wide variety of applications where conventional sampling methods would be difficult to implement. With further refinements, the method is capable of generating more detailed results in a cost-effective manor.

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7) R.B. Jacko, D.W. Neuendorf, and J.R. Blandford, "The By-Product Coke Oven Pushing Operation: Total and Trace Metal Particulate Emissions," Presented at APCA Annual Meeting, Portland, Oregon, 1976.

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STEEL MILL
PARTICULATE CHARACTERIZATION AND SOURCE/RECEPTOR ANALYSIS

U.S. Steel Corporation Geneva Plant

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ABSTRACT

This study (1) characterized particulate emissions from fugitive sources within a steel mill to determine their potential to be utilized as relatively unique environmental indicators and (2) determined their relative presence and quantity in the ambient environment within a region near the plant. Analyses were made using scanning electron microscopy/energy dispersive X-ray spectroscopy (SEM/EDS) and transmission electron microscopy/selected area electron diffraction (TEM/SAED). Distinct species of particulates were identified which could be useful in source/receptor analyses. These include carbon particles produced during coking, open hearth and blast furnace operations; iron spheres produced during blast furnace and open hearth operations; angular Fe and Fe-rich particulates produced during sintering plant operation; potassium-sulfur rich particle type produced only in the slag flush and slag tap sections of the blast furnace; and encapsulated iron particles produced by door leaks after slag charging. Examination of ambient samples further demonstrated that the carbonaceous particles and iron spheres produced by the steel mill were the best environmental indicators of the steel mill impact. Angular Fe and Fe-rich particulates were also useful indicators in the vicinity of the steel mill itself.

INTRODUCTION

It has been hypothesized that observed light scattering problems and high TSP levels in the Provo, Utah area are significantly affected by particulate emissions from the U.S. Steel Corporation (USSC), Geneva Plant, located north of Provo, Utah. The Materials Analysis Laboratory, Denver Research Institute, performed a particulate characterization of (1) source emissions from the USSC Geneva Plant, located north of Provo, Utah, and (2) ambient samples collected within the region to determine the feasibility of obtaining fugitive emission source/receptor information using microinventory analyses. Samples submitted for analysis were collected on 0.2 and 0.4 μm Nuclepore polycarbonate thin membrane filters in ∿ 7-10 LPM low volume air filter systems. Analyses were designed to provide definitive information on the composition and concentration of particulate species distributed on nuclepore substrates by using scanning (SEM) and transmission (TEM) electron microscopy, energy dispersive X-ray spectroscopy and selected area electron diffraction. The study was conducted in two phases: (1) the characterization of fugitive particulate emissions from sources within the steel plant to determine their potential to be utilized as relatively unique environmental indicators specific to the Geneva steel plant; and (2) determine the presence and quantity of such particulates in the ambient environment in the vicinity of the plant. Because the project was terminated for unspecified reasons prior to its completion, much of the material presented in this paper was derived independently by Denver Research Institute. At this date the exact locations of the ambient sampling sites have not been made available to the author.

METHODS AND MATERIALS

All samples were collected by the Environmental Protection Agency, National Enforcement Investigation Center, Denver, Colorado, during the fall of 1977. Particulates on thin membrane polycarbonate filters were examined "in situ" by coating excised portions of each filter with 20.0 nm of carbon by vacuum evaporation to make them conductive. Each sample was quickly examined for even particle distribution and then random portions of the filter were photographed at magnifications adequate to examine particles of interest. These particulates were simultaneously subjected to individual qualitative X-ray analysis; comments were recorded directly on photographs or separate notation sheets. The number of particulates examined on any photograph ranged from approximately 10 to 100; numerous photos were analyzed where practical to provide adequate sample sizes. X-ray emission spectra of typical and unusual particulate species were recorded for future reference.

Estimates of mass loadings were derived from measured particle size and the area observed. It was assumed for calculation purposes that all particles were spheres with a diameter estimated by averaging a particle's longest axis length and its most representative width at right angles to this axis. Specific gravity was assumed to be 2.0 for carbon, 2.4 for "CaS", 5.2 for Fe or Fe-rich, and 2.6 for "KS" particulates. Thus by using (1) the assumed specific gravity, (2) the number of particles located in a specific area(s) and (3) the estimated individual average particle volume it was possible to estimate mass loading in gm cm^{-2}.

Only high magnification photographs (5,000X and 10,000X) were used to analyze ambient samples, which restricted analyses to relatively small particles ($\sim < 5.0$ µm) for the purposes of this study. For particles less than 1.0 µm the procedure was to measure all of the particles in 20mm x 20mm grid placed on a series of randomly selected areas of a photograph. Average particle size was calculated and the total number of particles of a group in the area are entered into the equation (# of particles/cm^2) (avg. particle vol.-cm^3) (density-gm/cm^3) = gm cm^{-2}. For larger or less prevalent particles, a whole photograph or number of photographs were used instead of a portion of a filter.

Samples were also examined by transmission electron microscopy to provide higher resolution of very fine structural detail, interior particulate morphology and crystallinity (by electron diffraction). The process of membrane filter dissolution and subsequent examination are detailed in Ruud et al. (1976).

RESULTS

A. Source Samples

1. Coking Process

a) Door Emissions

Particulates observed on three samples were very sparse.. The particulates noted were spheres of carbon ranging from 0.5-2.5 μm in diameter. In one sample mineral particles approximately 2-5 μm in effective diameter were also observed.

b) Pushing

Emission observed on two samples contained virtually no particles.

c) Process Charging

No large particles on this sample. Some small carbon spheres 0.27 ± 0.11 μm in average diameter in low concentration 8.64 x 10^6 cm^{-2} were present. This is approximately 1.78 x 10^{-7} gm cm^{-2} assuming a specific gravity of 2.0.

d) Ambient Conditions Topside

Two samples were examined.

i) The first sample contained two morphologically different species of carbon particles (Figs. 1 and 2). The first were larger spheres 1.18 ± 0.41 μm in diameter in a concentration of 9.43 x 10^5 cm^{-2} which estimated to be 1.62 x 10^{-6} gm cm^{-2}. The second group of particles were smaller but more numerous with an average diameter of 0.15 ± 0.04 μm in a concentration of 1.5 x 10^9 cm^2 with an estimated mass concentration of 5.30 x 10^{-6} gm cm^{-2}. These smaller particles were often observed to be agglomerated. Both species contained trace amounts of Al, Si, S and Cr. The larger spheres were observed to usually be hollow when examined by the TEM (Fig. 3).

ii) Sample C-9-18 contained larger particles similar to those observed in C-13-21; however, the morphology of some of these particles was distorted in shape such as to suggest that they had been fluid at one time (Fig. 4).

e) Cap Leaks

Few particulates were observed on the sample examined.

2. Open Hearth

a) Door Leaks After Slag Charge

Mineral particulates (1-10μm) were observed in moderate

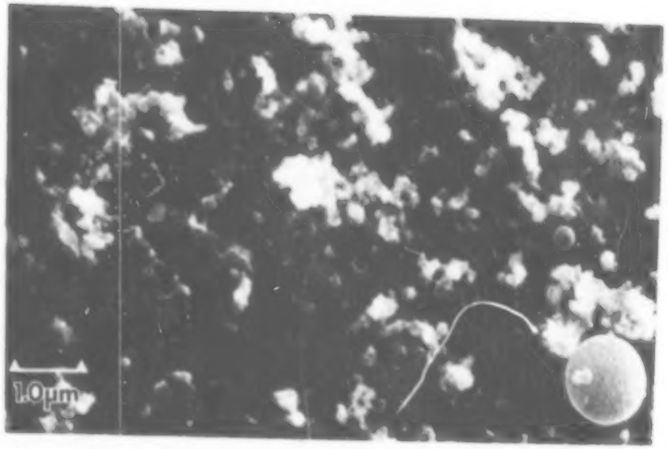


Fig. 1. SEM micrograph of coke particles, 10,000X.

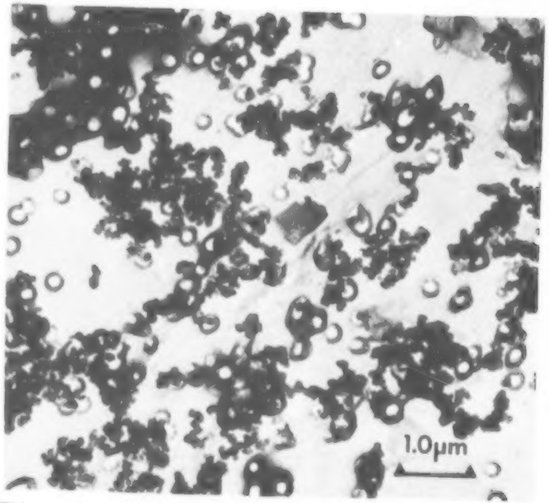


Fig. 2. TEM micrograph of coke particles, 10,000X.

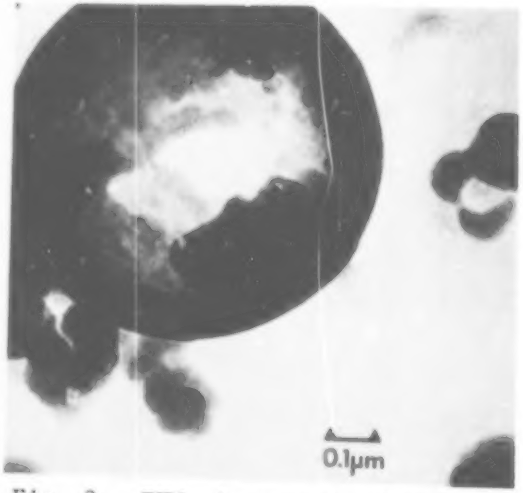


Fig. 3. TEM micrograph of two species of coke particles, 62,000X.

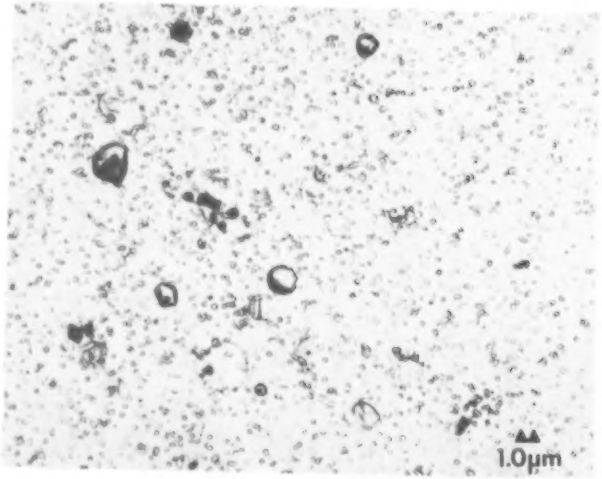


Fig. 4. TEM micrograph of "hollow" particles of coke, 2,000X.

concentrations, they contained various amounts of Si, Fe and Ca. The smaller particles (Fig. 5) contained Fe and carbon particles. The Fe particles have an "encapsulated" appearance with a size of 0.40 ± 0.17 μm, concentration of 1.26 x 10^7 cm^{-2} and mass concentration of 2.20 x 10^{-6} cm^{-2} assuming a specific gravity of 5.2 The carbon particles were somewhat spherical or plate-like and had a size of 0.28 ± 10 μm, concentrations of 1.29 x 10^8 cm^{-2} and mass of 2.97 x 10^{-6} gm cm^{-2}.

b) Ambient

The moderately loaded filters contained large (> 5.0 μm) Fe-rich mineral and Fe spherical particles. The smaller particles were similar in composition to the preceding sample.

c) Hot Metal Charge

This sample was heavily loaded with iron and carbon particles (Fig. 6). The larger Fe spheres (> 3 μm) were only distinguished from smaller Fe particles by the presence of more surface morphology: average size 4.07 ± 1.27 μm, concentration = 1.10 x 10^5 cm^{-2}, mass concentration = 2.02 x 10^{-5} gm cm^{-2}. The smaller Fe particulates (Fig. 7), which were somewhat spherical, had a mean size of 0.86 ± 43, concentration of 1.10 x 10^7 cm^{-2} and approximate mass of 1.90 x 10^{-5} gm cm^{-2}. The small carbon particles (e.g. those not indicated in Fig. 7) were highly concentrated in agglomerates; size was difficult to assess but was approximately 0.18 ± 0.09 μm, which gives a concentration of 9.50 x 10^8 cm^{-2} and a mass concentration of 5.80 x 10^{-6} gm cm^{-2}. TEM examination shows a relatively stable but relatively nonelectron dense film coating on all of these particles (Fig. 8).

d) Door Leaks

The samples contained only relatively light concentration of particles similar in composition to those produced in the hot metal charge. Some Fe particulates < 0.3 μm in diameter were observed.

e) Door Leaks During Slag Flush

Some large (1.0-5.0 μm) mineral particles were observed. These were mainly Ca with some Mg. Smaller carbon particles were observed in similar sizes and concentrations as the hot metal charge.

f) Scrubber

Particulates observed in association with the scrubber were again similar to the carbon produced by the hot metal charge but in lower concentrations. Some particulate agglomerates (1-5 μm) contained Fe, K, S. Many of the smaller particles (< 1.0 μm) had trace amounts of Fe or were composed of Fe.

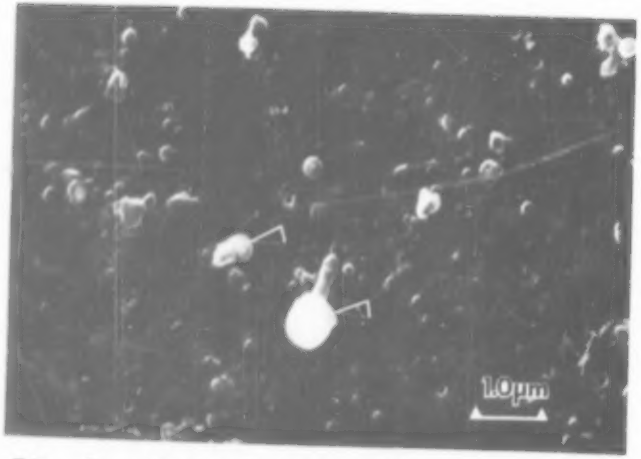


Fig. 5. SEM micrograph of "encapsulated iron particles produced by door leaks in the open hearth, 10,000X.

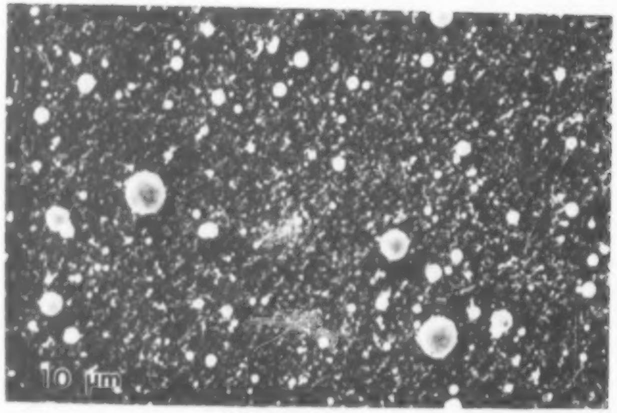


Fig. 6. SEM micrograph of particles produced during the hot metal charge process in the open hearth,1000X.

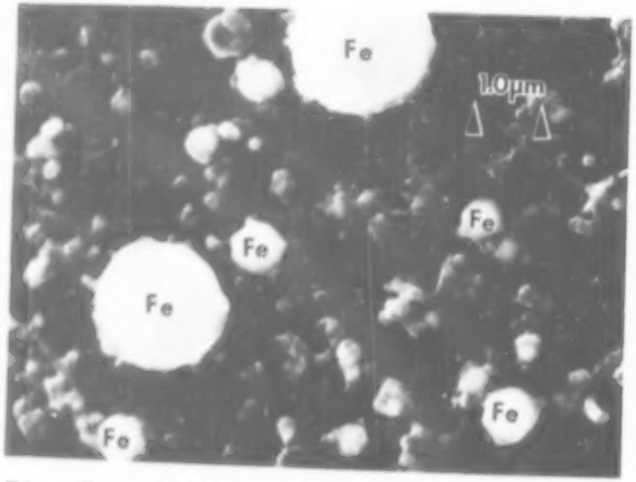


Fig. 7. SEM micrograph of particles produced during the hot metal charge process in the open hearth, 10,000X.

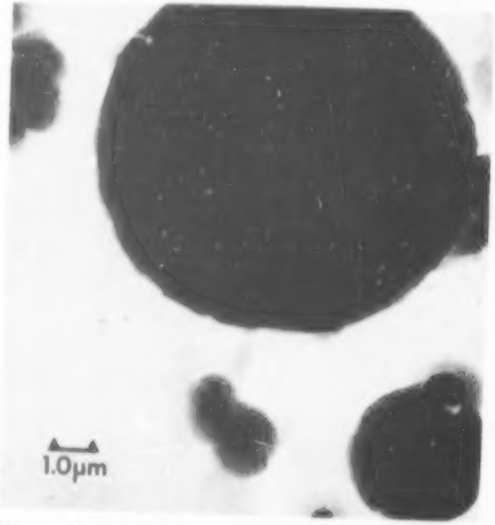


Fig. 8. TEM micrograph of open hearth particles, 62,000X.

g) Tap

This was a relatively lightly loaded sample. Some large particles (5-2 μm) of Ca mineral containing Mg, S and Si were observed. Smaller particles (< 1.0 μm) were mostly carbon but a few mineral types were also observed.

h) Limestone Charge

This sample contained particulates similar to the hot metal charge, but in reduced concentrations.

i) Slag Flush

Almost identical to those produced by hot metal charge, except less concentrated. Some spheres less than 1.0 μm were not rich in iron, however.

j) Bank Cleaning

No particles observed.

k) Fettle

No particles observed.

3. Blast Furnace

a) Slag Flush

Large spheres of Fe (∿ 90%) and Ca (∿ 10%): avg. size = 2.06 ± 1.01 μm, concentration = 1.41×10^5 cm^{-2} mass concentration = 3.36×10^{-6} gm cm^{-2} were observed. But numerous small particles rich in K and S (Fig. 9) dominated the sample. Morphology can be more easily observed in high resolution transmission electron microscope (Fig. 10). The average size was 0.24 ± 0.15 μm, concentration = 1.49×10^9 cm^{-2} and mass concentration - 2.80×10^{-5} gm cm^{-2} assuming a specific gravity of 2.6. The material produces an electron diffraction pattern and is therefore crystalline. The particles were also observed to partially disintegrate in an intense focused electron beam.

b) Hot Metal Tap

Lightly loaded - a few large Fe spherical particles similar to those found on the slag flush sample. Carbon associated with this sample is composed of agglomerates of carbon made up of particulates < 0.1 μm in diameter.

c) Hot Metal Runner

Filter virtually without particles.

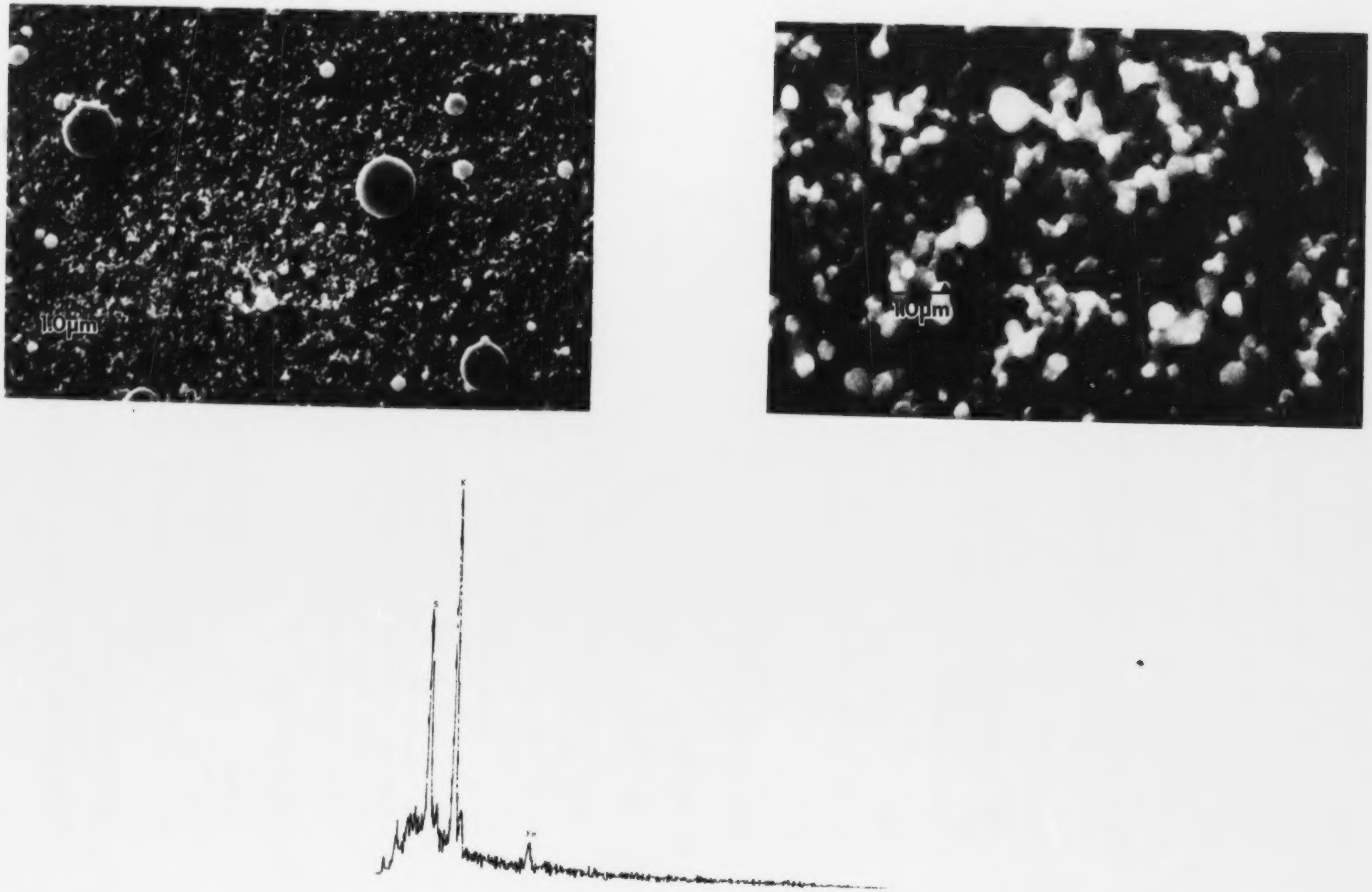

1.0µm
1.0µm
S
K
Fe

Fig. 9. SEM micrographs (1,000X and 10,000X) and X-ray spectra of particles produced during blast furnace slag flush operations.

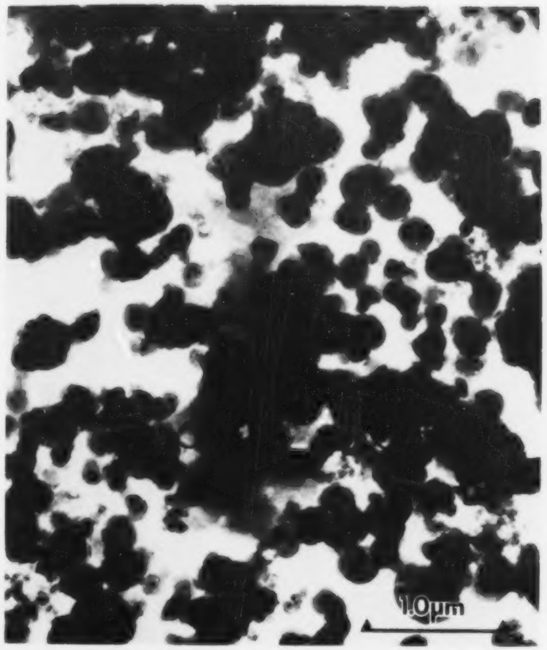


Fig. 10. TEM micrograph of particles produced during blast furnace slag flush operations, 23,000X.

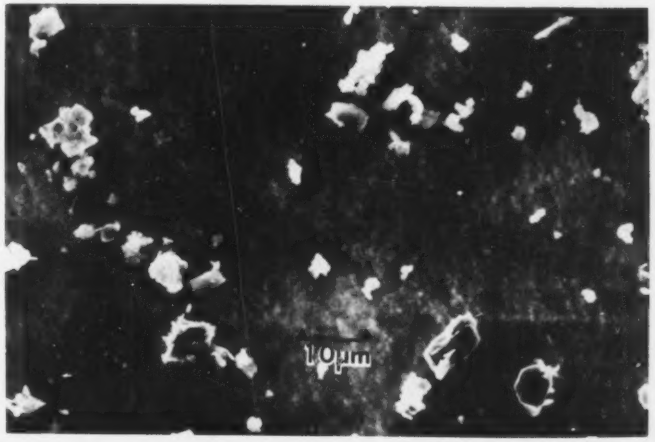


Fig. 11. SEM micrograph of particles produced during sintering plant operations. 1000X.

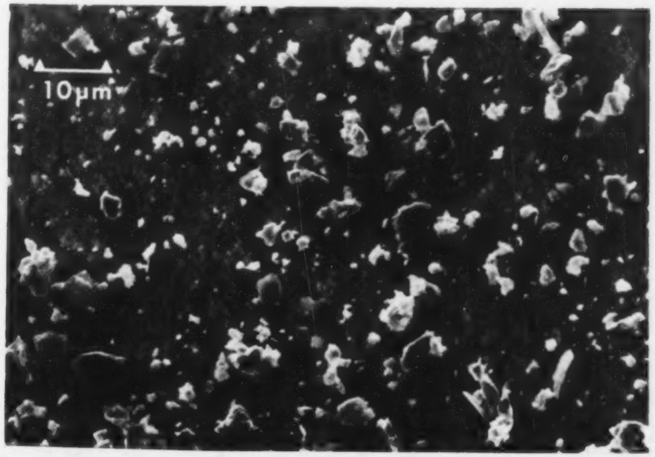


Fig. 12. SEM micrograph of particles produced during crushing operatins at the Heckett Engineering site, 1000X.

d) Slag Tap

Sample composition almost identical to Slag Flush but contains more large Fe spheres. Surface of these spheres morphologically smoother than those being produced in the open hearth. Average size = 1.74 ± 1.29, concentration = 1.26×10^6 cm^{-2}, mass concentration = 1.81×10^{-5} gms cm^{-2}.

4. Sintering Plant

All sintering plant samples were characterized by the almost total lack of carbon particles, spherical particles and particles less than 1.0 µm. The samples contained large angular particles (Fig. 11) rich in Ca and/or Fe. If we assume an average density of 4.0 the estimated avg. size = 4.03 ± 2.35 µm and concentration - 7.77×10^5 cm^{-2}, the mass concentration is estimated at 1.07×10^{-4} gm cm^{-2}. Some large particulates of carbon or coal were also observed.

5. Heckett Engineering

Overall, all samples collected in Heckett Engineering location contained almost exclusively large particles of a mineral composition (i.e. calcites and silicates); small (< 1.0 µm) carbon or Fe particles were not observed on any of these samples (Fig. 12). The predominant species was a calcium silicate (Figs. 13 and 14), similar in composition to the minerals epidote and dolomite.

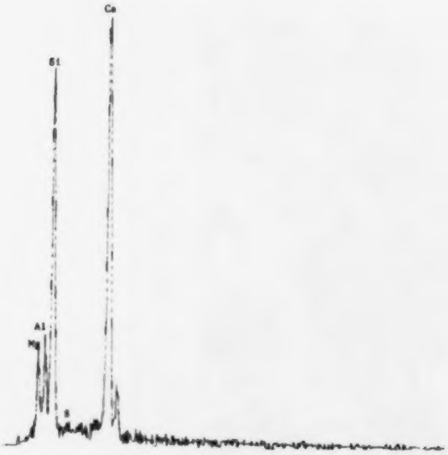


Fig. 13. Typical x-ray spectra of an individual particle collected during crushing operations.

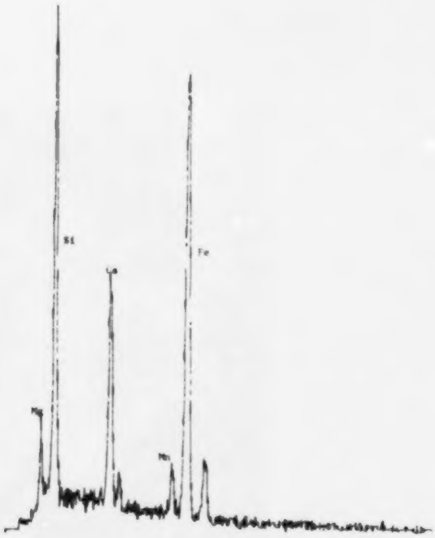


Fig. 14. Typical x-ray spectra of an individual particle collected during crushing operations.

B. Ambient Samples

Specific information on ambient sample sites has not been made available at this time.

1. Station 1

All samples for this sampling site were heavily loaded. Overall X-ray emission spectra for November 7. 13, 16 and 18 are presented in Figure 15. From this information it is readily observable that elemental sulfur became most abundant on November 16 and elemental iron on November 18 (one of the highest levels observed on ambient samples). In both cases this is the result of relatively large particles containing calcium and sulfur or, respectively, Fe-rich minerals.

2. Station 2

The November 8 sample was heavily loaded with large mineral particles which were mainly calcium silicates and silicon (quartz). One very large Fe sphere (9 μm) was observed. Iron and iron-rich particles were observed in sizes greater than and less than 1.0 μm in diameter. Particles rich in sulfur were also observed, sometimes with trace amounts of elemental lead. Some micron size spheres of carbon were also observed. Sulfur was associated with carbon particles and was very high in concentration producing an overall high bulk sample sulfur concentration (Fig. 16). The November 11 sample was much less

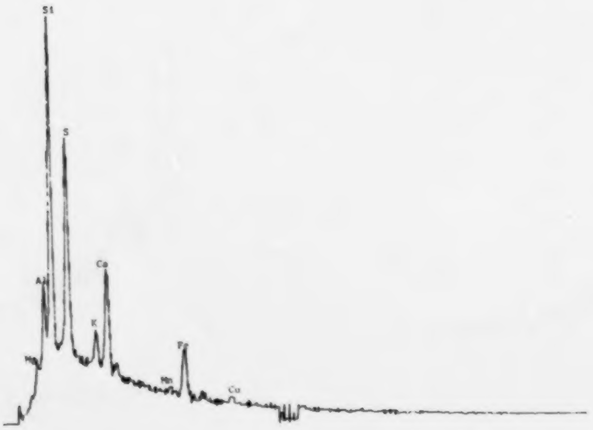
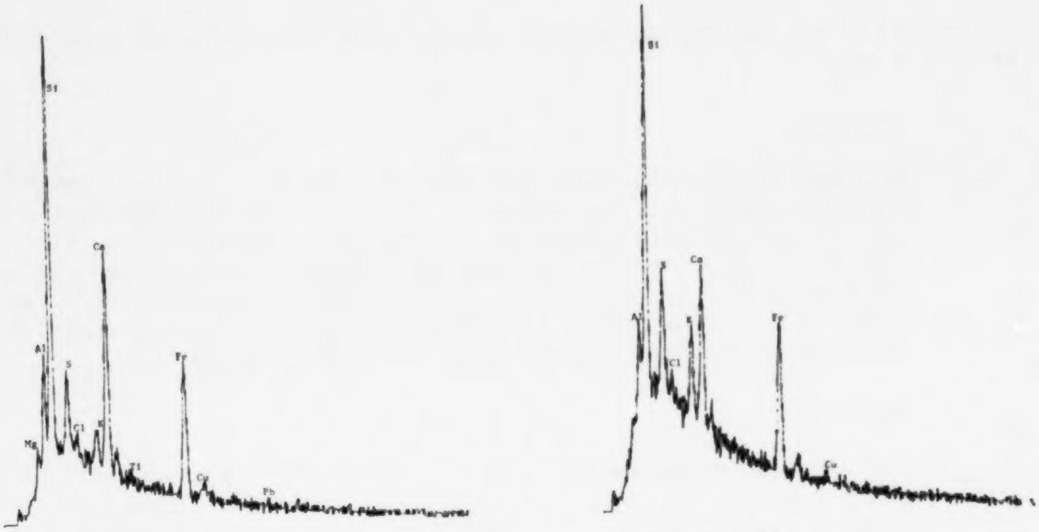
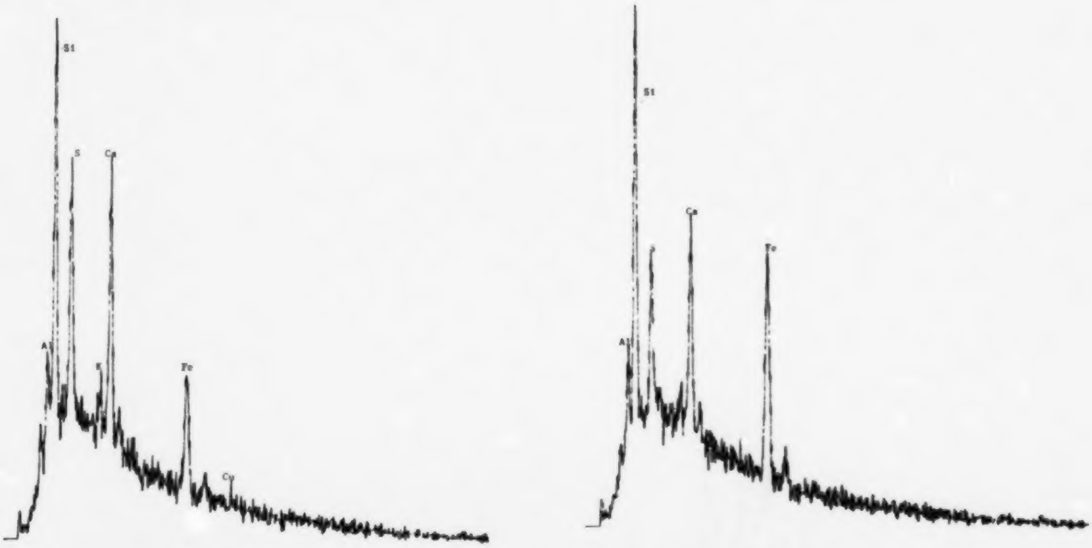


Fig. 16. X-ray bulk spectra from particulates collected November 11, at site 2.



November 7

November 13



November 16

November 18

Fig. 15. X-ray spectra of bulk samples collected at ambient site 1, November 7, 13, 16 and 18, 1977

heavily loaded but contained relatively more large (> 1.0 μm) iron particles than the November 8th sample.

The November 14 sample was virtually void of particulates and no Fe-rich particles were observed.

The November 17 sample contained a moderate particulate load. Most of the larger particles were calcium or calcium silicates. A few Fe spheres about 2.0 μm were observed. Only a few small (< 1.0 μm) Fe particles were noted.

3. Station 3

The November 9 sample was heavily loaded. The larger particulates were almost entirely mineral. Two species of iron particles: individual spheres approximately 0.5 μm in diameter and agglomerates of particles < 0.2 μm in diameter were observed.

The November 12 sample was less heavily loaded, contained a large Fe sphere 2 μm in diameter and contained less small (< 1.0 μm) Fe particulates than the November 9 sample. Relatively high concentrations of sulfur were observed with the small carbon particulates.

The November 15 sample was similar in composition to November 12 except for reduced amounts of material.

The November 18 sample exhibited increased amounts of material. There was a significant increase in the observed number of large Fe mineral particles. Small Fe particles were also present as 0.2 μm spheres. Sulfur-rich particles were observed; the morphology was consistent with carbon particles observed earlier.

4. Station 4

The November 8 sample was heavily loaded. Large angular particles of Fe and Fe silicates were observed as well as a few Fe spheres. Small particulates included Fe and Fe silicates; a few particles rich in Cu and Zn were also observed.

The November 11 sample contained only a few large particles (none over 3-4 μm in length). The small particles were predominantly carbon spheres < 2.0 μm and carbon plates/spheres; one agglomerate of Fe particles was observed.

The November 14 sample was very clean. No small Fe particles were observed, and the number of carbon particulates was greatly reduced.

An increase in particulate loading on the November 17 sample was obvious. The large angular particulate fraction contained a high proportion of Fe or Fe-rich particulates. An increase in small carbon and Fe spheres (∿ 0.2 μm) was also evident at higher magnifications.

5. Station 5

Samples collected on November 7 and 10 were heavily loaded with large particles (Figs. 17 and 18). The sample collected November 13 (Fig. 19) was less loaded and the sample collected November 16 had virtually no particulates of any kind.

On November 7 some of the larger angular particulates contained Fe or Fe silicates which were 4.97 ± 1.75 μm in average effective diameter. Carbon particulates of two distinct types were observed at higher magnification (Fig. 18); iron-rich particles were present in relatively low concentrations.

No iron silicates were observed in the sample collected November 10; however, Fe particulates were observed, most were spherical (∿ 2.0 μm) in shape.

The November 13th sample was lightly loaded but did contain a number of angular particulates ∿ 1.0 μm which were mostly mineral silicates although some were carbon and iron (pollen was also present). Some carbon spheres approximately 1 μm in diameter were observed. Particulates < 1.0 μm were present in very low concentration, and only one submicron Fe particle was observed.

6. Station 6

The November 12th sample was unique in that it contained a number of large flyash and carbon particles with high concentrations of potassium. Some spheres containing Fe were noted. The smaller size particle fraction contained Fe (0.2 μm) and sulfur-rich carbon particulates.

The November 18th sample was void of particles > 2 μm and contained only a few carbon and Fe particles about 0.2 μm.

7. Station 8

Samples were collected at this location consecutively from November 7th through 18th. Particle loading was heavy the 7th and increased the 8th. Some reduction was noted the 9th and 10th; the 11th and 12th exhibited even heavier loads. Some reduction was noted the 13th; and by the 14th the level of particulates had been reduced most significantly. From the 15th through the 18th the amounts of material continued to rise to levels experienced November 7.

Most of the large particulates noted on the 7th were mineral; none were Fe and only a small percent were Fe rich. A significant number of spheres > 1.0 μm were observed which were composed of carbon but also contained a significant amount of K; others were siliceous or PbBrCl. The smaller particulates observed were carbon (0.1 μm); some spheres (∿ 0.6 μm) of carbon, and Fe (0.3 μm) were also observed. Material rich in sulfur was also present.

The sample collected the 8th was very heavily loaded but had a composition similar to that of the previous day (Fig. 20). More carbon

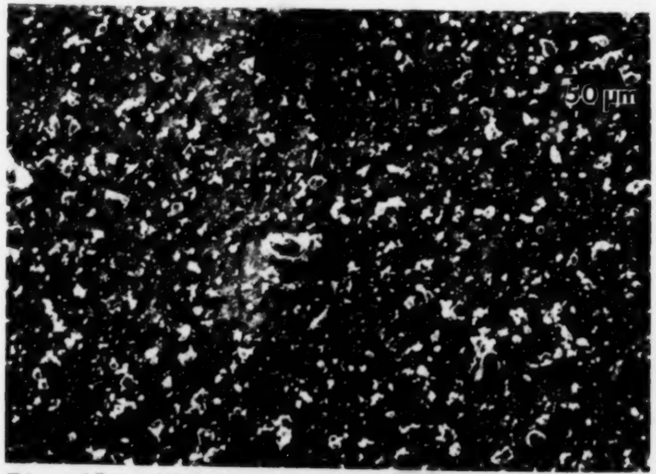


Fig. 17. SEM micrograph, Ambient Site 5, November 7, 200X.

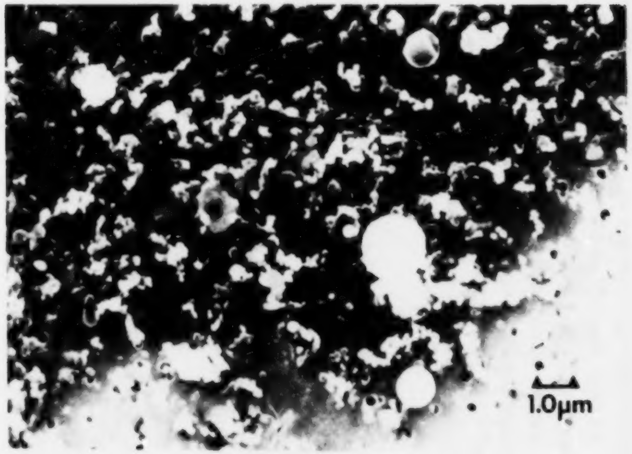


Fig. 18. SEM micrograph, Ambient Site 5, November 7, 5,000X.

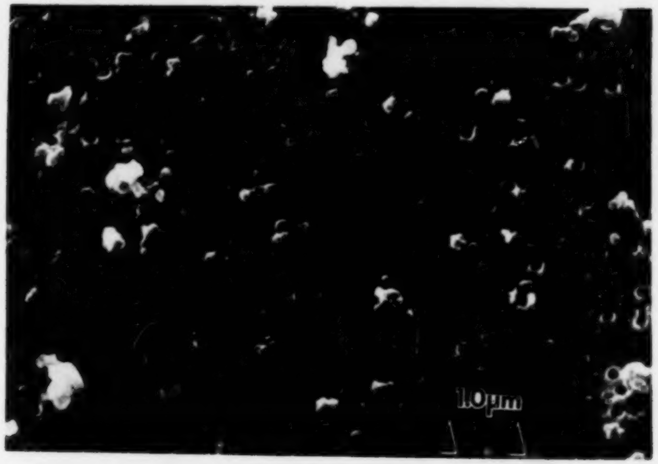


Fig. 19. SEM micrograph, Ambient Site 5, November 13, 10,000X.

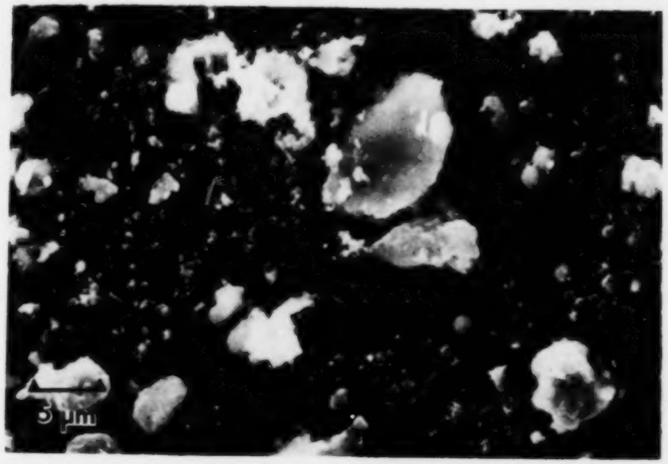


Fig. 20. SEM micrograph, Ambient Site 8, November 8th, 2,000X.

particulates (0.5 μm) were evident than previously observed; these, and the finer carbon particulates, contained trace amounts of sulfur. This proportion of particulates remained the same through the 13th. On the 11th no large Fe or Fe-rich particulates were observed, though the sample was heavily loaded; the small Fe particulates, e.g. Fig. 21, had a mass concentration of 5.95×10^{-5} gm cm^{-2}. The amount of sulfur associated with the numerous carbon particles was observed to have increased since November 8th.

The 13th, one large (3.6 μm) Fe sphere in a 1000X field was observed.

The November 14th sample was the cleanest of Station 8. However, iron spheres (1-2.5 μm) were observed, as well as some small (< 1.0 μm) Fe particles. Particulates observed on the 15th were similar to those of the 14th; some particles (∿ 0.5 μm) containing calcium and sulfur were also observed.

The large particle fractions of sample 16 were predominantly mineral and carbon (automotive); a few Fe spheres and Ca-S particles were observed. A few submicron Fe and Ca-S particles were also observed. Figure 22 illustrates some of the typical small particles observed on this sample.

Samples collected on the 17th and 18th are very similar to those collected the 16th with a slight increase in concentration.

8. Station 9

Samples were collected consecutively from November 8th through the 17th. The most distinctive feature of these samples is that no large Fe particles are observed (only one large angular Fe-rich particle was observed in all the samples). A few micron size Fe particles were observed in the sample collected November 17th. Particulate loading was heaviest November 8-11, reducing in amount through the 12th and 13th to a low level the 14th which then remained relatively continuous through the 17th. Submicron size particles rich in copper and lead-arsenic were observed in a number of samples.

On November 9th, large carbon particles 2.92 ± 1.31 μm and smaller particles > 1.0 μm were observed. Figure 23 illustrates some of these particle types. Sulfur was observed to be associated with both carbon types.

9. Station 10

November 8 and 9 - very heavy loading. Though large clay (Al,Si,K,Ca, Fe) and quartz particles were present, the filters were observed to also contain high concentrations of small particles. Most of the submicron size carbon particles were rich in sulfur, producing a high sulfur concentration for the entire sample (Fig. 24).

November 10 and 11 - heavily loaded but reduced from the 8th and 9th. Large particles still predominant, but some large carbon particles apparent. More larger (.4-1.0 μm) submicron size particles observed;

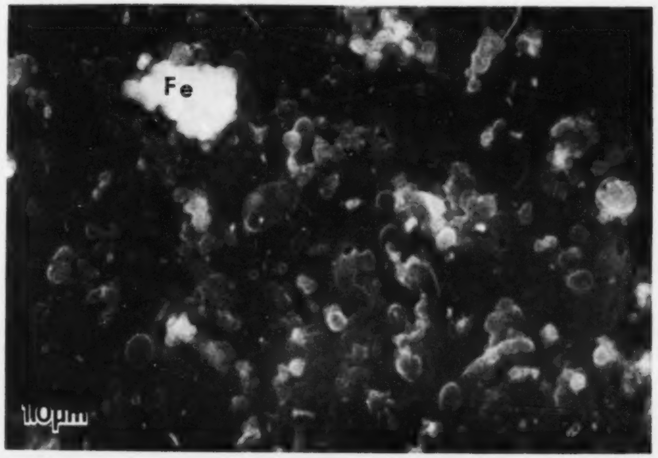


Fig. 21. SEM micrograph, Ambient Site 8, November 11th, 10,000X.

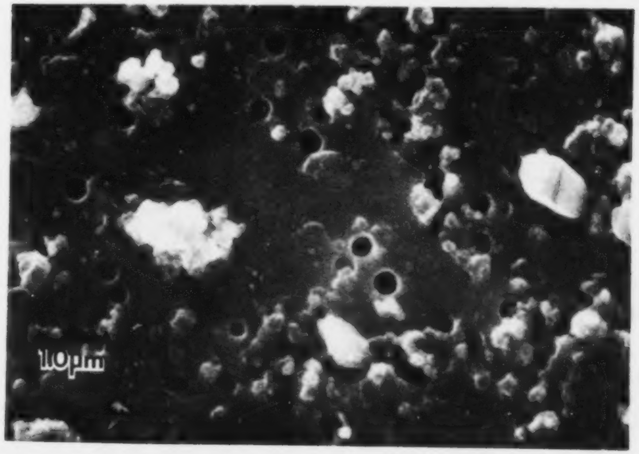


Fig. 22. SEM micrograph, Ambient Site 8, November 16th, 10,000X.

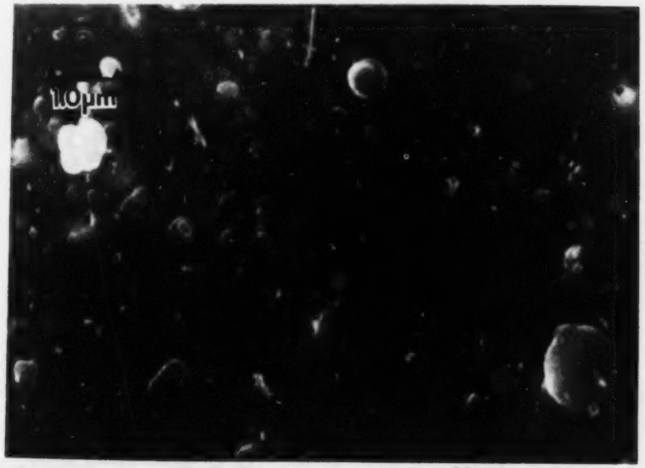


Fig. 23. SEM micrograph, Ambient Site 9, November 11th, 10,000X.

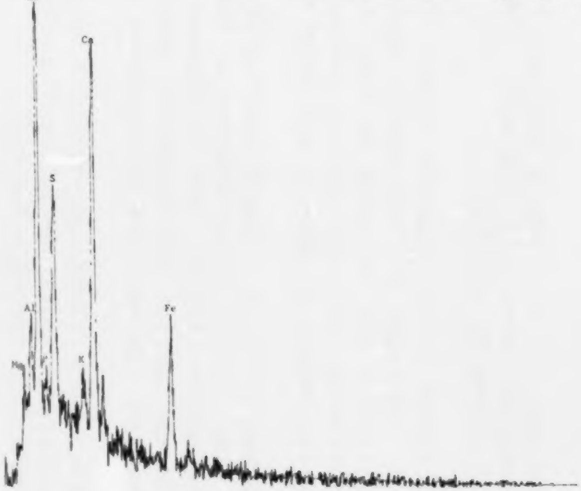


Fig. 24. X-ray spectra from a bulk sample collected from ambient sampling site 10, November 9. The sulfur peak is produced by sulfur adsorbed onto carbon particles.

they are probably carbon with adsorbed sulfur; some iron agglomerates also present (Fig. 25). Overall sulfur concentration was the highest of any ambient or source sample on sample 10 and was almost entirely associated with particles less than one micrometer in average diameter. By November 11th, sulfur concentration had been reduced to 1/3 of that of the 10th.

November 12-13 - sample loading reduced from the previous samples; composition essentially the same. Individual small particles (∿ 0.5 μm) of Fe and Cu observed.

November 14-15 - Samples lightly loaded. On the 14th, only small (0.1 μm) and large (0.5 μm) carbon particles were observed. By the 15th, particles had increased in concentration; small (< 0.5 μm) Fe particles were also observed. Carbon particles contained only traces of sulfur. A few submicron size Cu particles were observed on the 15th.

November 16-18 - Sample loading became progressively heavier after the 15th. Particulates observed in the larger size fraction continued to be mainly mineral, some Fe spheres and Fe-rich angular particulates. In the smaller size fraction, carbon particulates were observed to increase. Fe and Ca-S particulates were also observed.

Estimated filter concentration values for large and small carbon particulates and iron-rich particulates spherical in morphology are presented in Appendix Table A.

DISCUSSION

The following particulates produced by the U.S. Steel Corporation, Geneva Plant could be potentially useful in assessing fugitive source emissions from specific areas within the plant:

1. Carbon particulates small spheres approximately 0.1 μm in diameter, often found in agglomerates, are produced during the coking, open hearth and blast furnace processes. Particulates of this type were observed in all ambient samples. However, there are other sources for these particulates, notably the automobile. Careful analysis would be required to use these as source emissions indicator.

2. Carbon particulates approximately 1.0 μm in diameter having a definite spherical shape are produced during the coking process. These particulates were observed at most ambient stations, usually in low concentrations. They are apparently unique to the Geneva Steel Works.

3. Carbon particulates - spheres or plate-like particles ∿ 0.30 μm in diameter produced by door leaks after slag charge. Similar particulates have been observed at a number of ambient sites. They are apparently somewhat unique, although they might be indistinguishable from some particulates produced during coking operation.

4. Iron spheres - spheres containing mainly Fe produced in a size range from > 5 μm to < 0.3 μm. The most productive source is probably the hot metal

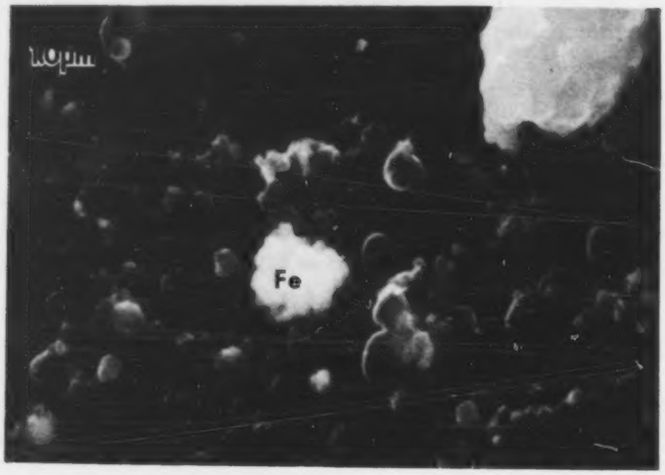


Fig. 25. SEM micrograph, Ambient Site 10, November 10, 10,000X.

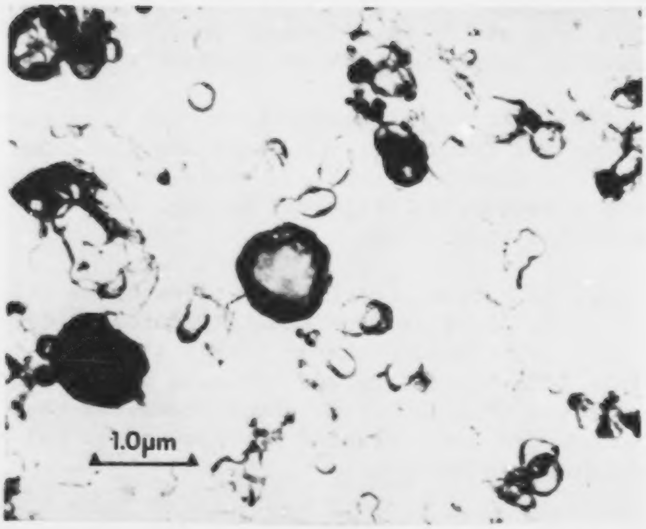


Fig. 26. TEM micrograph, Ambient Site 10, sulfur-rich carbon particle, 20,000X.

charge section of the blast furnace, although these particles are produced in other open hearth and blast furnace sections. They are unique to the plant. The larger (> 1.0 μm) spheres produced in the open hearth and blast furnace areas may be morphologically different. Such iron spheres both large and small are found in low concentrations in almost all ambient samples.

5. Potassium-sulfur particulates 0.2 μm in diameter are produced only in the slag flush and slag tap sections of the blast furnace. They are unique to the steel plant. However, similar particles were found rarely only in a few ambient samples.

6. Large Fe and Fe-rich angular particles > 2.0 μm in effective diameter are produced during sintering plant operations. These particles could be used as a source indicator, but cannot be considered unique. A carefully applied statistical program coupled with meteorological information would be required to assess their potential as a spot source indicator.

7. "Encapsulated" iron particles (0.4 μm) produced during door leaks after slag charge. These particulates have a non-spherical structure, and morphological "halo" surround a central core. Similar particulates have been found in some ambient samples.

Carbon particles are usually identified by their conspicuous lack of elements with an atomic number greater than sodium. An observation made at all ambient sites was that the levels of sulfur associated with these types of particles were dependent upon the length of time that the local air mass had remained stagnant. In Figure 26, a TEM micrograph of one of the sulfur-rich carbon samples is displayed; these particles did not produce an electron diffraction pattern and were stable in a focused beam. No morphological differences were noted between particles with and without a sulfur association.[1]

A separate analysis for large angular iron-rich mineral particles was conducted to determine the feasibility of using the sintering plant fugitive emissions as a local specific indicator. A table of these data is provided in Appendix Table B and a summary is presented in Fig. 27. Sites 5 and 9 are respectively close to the steel plant.

On about November 13 a storm front moved through the region. Using mass estimated (Appendix Table A) it is possible to examine changes in particulate concentration probably associated with the Geneva Steel Plant operation as the air mass in the Provo area is cleared and the rate at which these particulates return to previous levels (Fig. 28). It should be noted that at this stage of refinement these values are not corrected for flow rates and sample times and are therefore comparative in nature.

1/ This topic is covered in more detail in Russell (1979).

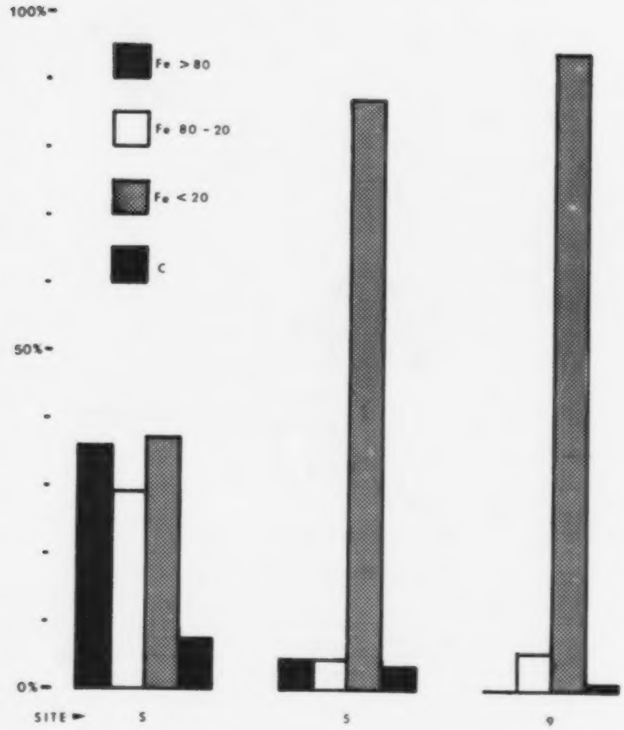


Fig. 27. Particle analysis for iron rich species.

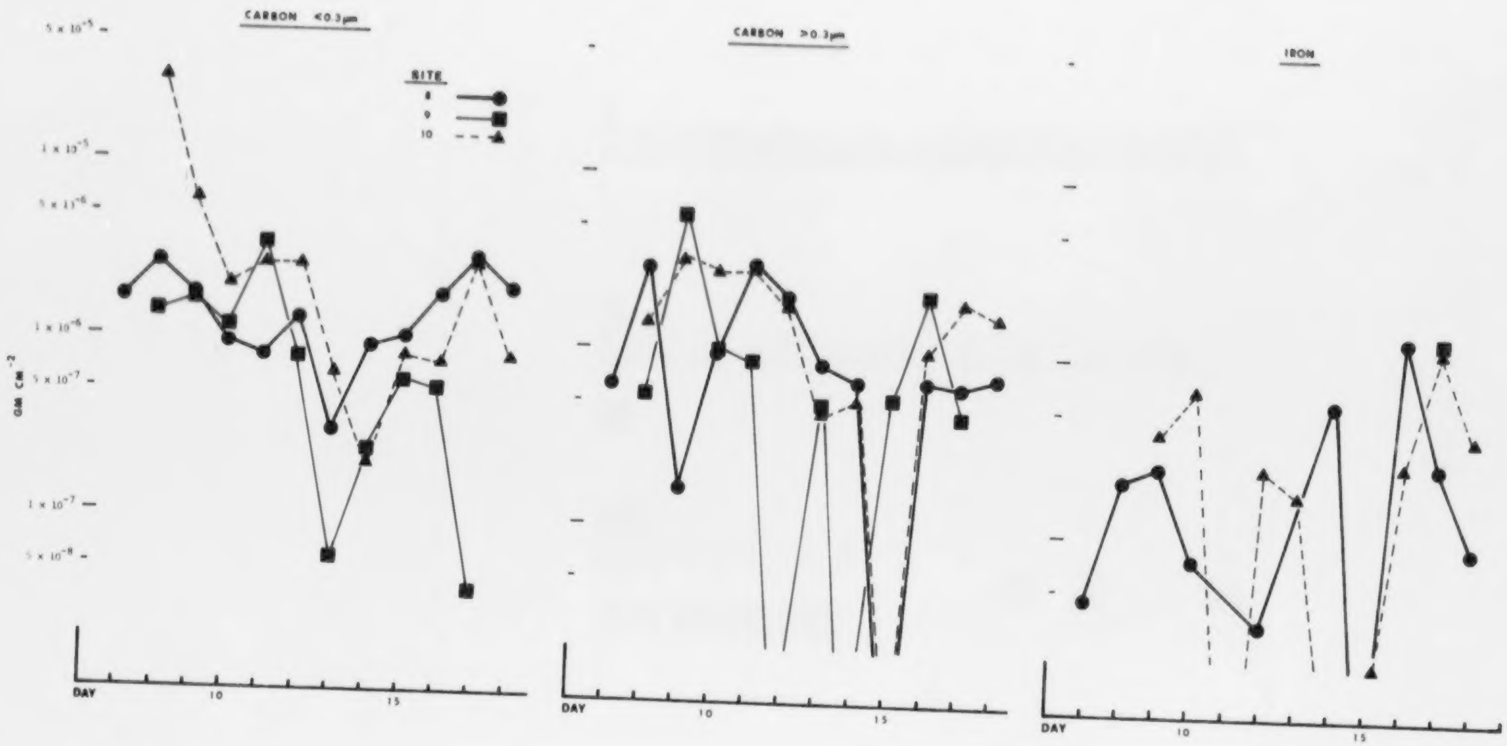


Fig. 28. Ambient particle analysis summation.

CONCLUSION

A microscopic inventory of particulates can provide invaluable assistance in assessing the nature and inhomogeneities of fugitive source emitters. Particles that are, in turn, unique can be identified some distance from the emitter. With suitable sampling parameters, estimates can be made for number and mass per unit of air.

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APPENDIX A

MASS ANALYSIS OF PARTICLES COLLECTED ON AMBIENT THIN MEMBRANE SUBSTRATES

Appendix Table A

Estimated mass collected on ambient site thin membrane filters

	Estimated Mass (gm cm^{-2})			
Sample	Carbon (< 0.3 μm)	Carbon (> 0.3 μm)	Fe	Other
1-7	3.02×10^{-6}	1.11×10^{-6}	1.37×10^{-5}	8.84×10^{-7} (PbBrCl)
1-13	3.18×10^{-6}	1.23×10^{-6}	1.50×10^{-6}	4.69×10^{-7} (flyash)
1-16	2.39×10^{-6}	2.09×10^{-6}	1.17×10^{-6}	
1-18	1.75×10^{-6}	1.84×10^{-6}	1.34×10^{-6}	
2-8	$2.71 \pm 0.91 \times 10^{-6}$	--	3.26×10^{-6}	--
2-11	$1.05 \pm 0.66 \times 10^{-6}$	--	1.39×10^{-7}	--
2-14	1.13×10^{-7}	--	--	--
2-17	$1.01 \pm 0.41 \times 10^{-6}$	--	2.26×10^{-7}	--
3-9	2.19×10^{-6}	8.03×10^{-7}	4.69×10^{-6}	--
3-12	1.33×10^{-6}	1.01×10^{-6}	1.25×10^{-6}	--
3-15	5.62×10^{-7}	6.26×10^{-7}	8.25×10^{-7}	--
3-18	6.22×10^{-7}	1.37×10^{-7}	3.19×10^{-7}	--
4-8	$\sim 5.0 \times 10^{-7}$	1.50×10^{-6}	1.82×10^{-5} (Fe-rich mineral)	--
4-11	1.21×10^{-6}	2.07×10^{-6}	1.78×10^{-7}	--
4-14	5.47×10^{-7}	1.50×10^{-7}	--	--
4-17	1.18×10^{-6}	2.37×10^{-7}	8.67×10^{-8}	--
5-7	$4.70 \pm 0.73 \times 10^{-6}$	2.34×10^{-6}	7.80×10^{-7}	--
5-10	$7.56 \pm 0.27 \times 10^{-7}$	2.99×10^{-7}	3.74×10^{-7}	--
5-13	$2.12 \pm 0.71 \times 10^{-7}$	--	--	--
5-16	2.25×10^{-8}	--	--	--
6-12	5.32×10^{-7}	2.44×10^{-7}	1.37×10^{-7}	3.19×10^{-6} (mineral)
6-18	9.22×10^{-8}	--	1.71×10^{-8}	
8-7	1.67×10^{-6}	6.07×10^{-7}	4.46×10^{-8}	--
8-8	2.60×10^{-6}	2.84×10^{-6}	2.06×10^{-7}	--
8-9	1.76×10^{-6}	1.57×10^{-7}	3.14×10^{-7}	--
8-10	9.35×10^{-7}	9.25×10^{-7}	7.64×10^{-8}	--
8-11	8.17×10^{-7}	3.01×10^{-6}	1.12×10^{-6} (1 lrg. part.)	--
8-12	1.42×10^{-6}	1.93×10^{-6}	3.25×10^{-8}	--
8-13	3.03×10^{-7}	8.07×10^{-7}	2.31×10^{-7} (1 part.)	

Appendix Table A (Con't)

	Estimated Mass (gm cm^{-2}			
Sample	Carbon (< 0.3 μm)	Carbon (> 0.3 μm)	Fe	Other
8-14	9.28×10^{-7}	6.57×10^{-7}	6.19×10^{-7}	
8-15	1.06×10^{-6}	--	--	3.61×10^{-7} ("CaS")
8-16	1.82×10^{-6}	6.80×10^{-7}	1.44×10^{-6}	1.07×10^{-6} ("CaS")
8-17	2.98×10^{-6}	6.12×10^{-7}	2.77×10^{-7}	2.43×10^{-6} ("CaS")
8-18	1.99×10^{-6}	6.44×10^{-7}	9.17×10^{-8}	6.90×10^{-7} ("CaS")
9-8	1.40×10^{-6}	5.30×10^{-7}	--	--
9-9	1.66×10^{-6}	5.67×10^{-6}	--	--
9-10	1.19×10^{-6}	9.30×10^{-7}	--	--
9-11	3.35×10^{-6}	8.42×10^{-7}	--	--
9-12	7.79×10^{-7}	--	--	1.32×10^{-8} (Cu)
9-13	5.77×10^{-8}	4.87×10^{-7}	--	1.32×10^{-5} (Cu - 1 part.)
9-14	2.42×10^{-7}	--	--	--
9-15	6.02×10^{-7}	5.47×10^{-7}	--	--
9-16	5.24×10^{-7}	2.13×10^{-6}	--	--
9-17	3.37×10^{-8}	4.21×10^{-7}	1.43×10^{-6}	--
10-8	$2.87 \pm 0.81 \times 10^{-5}$	1.43×10^{-6}	--	--
10-9	$5.98 \pm 0.04 \times 10^{-6}$	3.37×10^{-6}	4.02×10^{-7}	--
10-10	2.03×10^{-6}	2.78×10^{-6}	7.13×10^{-7}	--
10-11	2.62×10^{-6}	2.81×10^{-6}	--	--
10-12	2.69×10^{-6}	1.07×10^{-6}	2.45×10^{-7}	--
10-13	6.43×10^{-7}	4.52×10^{-7}	1.78×10^{-7}	--
10-14	1.95×10^{-7}	5.25×10^{-7}	--	--
10-15	8.17×10^{-7}	--	1.96×10^{-8}	--
10-16	7.75×10^{-7}	1.01×10^{-6}	2.79×10^{-7}	--
10-17	2.81×10^{-6}	1.87×10^{-6}	1.30×10^{-6}	--
10-18	7.96×10^{-7}	1.63×10^{-6}	4.08×10^{-7}	--

APPENDIX B

ANALYSIS OF IRON-RICH MINERAL PARTICULATES

Appendix Table B

Analyses of particles $\geq 5.0\mu m$ on thin membrane samples
S-10-6, 5-7 and 9-3 from Geneva Steel Works

Sample	Composition (% of particulate)										
	Fe > 80%	20%-50% Fe				Fe < 20%					
		Si	Si & Ca	Ca	Total	Si	Si & Ca	Ca	Other	Total	Carbon
S-10-6	35.9	11.5	6.5	1.3	19.3	19.2	7.7	6.4	2.8	37.1	7.7
5-7	4.8	2.4	2.4	0	4.8	25.0	35.7	22.6	3.6	86.9	3.6
9-13	0	4.8	0	0	4.8	39.3	13.1	40.5	1.2	94.1	1.2

DEVELOPMENT OF HORIZONTAL ELUTRIATORS FOR SAMPLING INHALABLE PARTICULATE FUGITIVE EMISSIONS

by

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ABSTRACT

The U.S. Environmental Protection Agency (EPA) is required, under the amended Clean Air Act of 1977, to review the scientific basis for the total suspended particulate (TSP) ambient air quality standard and determine whether a revised particulate standard can be promulgated by December, 1980. It has been recommended that research to develop information for a size-specific standard should focus on inhalable particulate (IP) matter as defined as airborne particles ≤ 15 µm aerodynamic diameter. This particle size range relates to that fraction of particulate matter which can primarily deposit in the conducting airways and the gas exchange areas of the human respiratory system during mouth breathing.

This paper addresses the efforts of Southern Research Institute under contract to IERL/EPA/RTP to experimentally apply horizontal elutriation to specific methods for sampling instack, ambient, and fugitive inhalable particulate emissions. Theoretical and experimental data are shown. Results of the application of horizontal elutriation for the initial collection stage of the Fugitive Assessment Sampling Train (FAST) developed by TRC Environmental Consultants are presented.

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is required under the amended Clean Air Act of 1977, to review the scientific basis for the total suspended particulate (TSP) ambient air quality standard and determine whether a revised particulate standard can be promulgated by December 1980. It has been recommended that research to develop information for a size-specific standard should focus on inhalable particulate (IP) matter as defined as airborne particles ≤ 15 μm aerodynamic diameter[1]. This particle size range relates to that fraction of particulate matter which can primarily deposit in the conducting airways and gas exchange areas of the human respiratory system during mouth breathing. Figures 1 and 2 present some of the data which led to the specification of the 15 μm IP size standard. While 100% deposition of particles during nose breathing occurs above 10 μm aerodynamic diameter, the 100% deposition size for mouth breathing is approximately 15 μm aerodynamic diameter.[1] An ideal IP sampler would then separate those fractions of particulate matter larger and smaller than 15 μm aerodynamic diameter.

Figure 3 presents the performance criteria for IP samplers. It was developed after extensive discussions between EPA staff members and scientists knowledgeable in particle sampling methods.[8] All samples will be required to fall within the performance specification indicated by the region shown in Figure 3. It is constructed by plotting two lognormal curves, with geometric standard deviations of 1.0 and 1.7 through the 15 μm ± 2 μm 50% points. After allowing 10% wall loss for small particles and 10% penetration of large particles, the area is completely defined. The tolerance in the D_{50} is 15 μm ± 2 μm.

Theoretical Considerations

A variety of aerosol sampling systems are being developed for use in measuring the concentration of inhalable particulate (IP). The primary performance requirement is that each system must separate particles larger and smaller than 15 μm aerodynamic diameter according to the specified efficiency curve.

Cyclones, impactors, virtual impactors, and horizontal elutriators are devices that possibly can be used to collect the larger particles. All of these, however, have features that limit their applicability. Impactors may not retain particles efficiently that are much larger than the stage cut point. The particles bounce and are reentrained into the gas stream, resulting in contamination of the small particle fraction.[9,10,11] Cyclones are not subject to that problem but they are larger and their performance is difficult to predict.[12] Virtual impactors may have significant losses of small particles.[13] Horizontal elutriators are bulky and their performance is sensitive to orientation. However, for reasonable velocities reentrainment is not a problem in horizontal elutriators and the theory describing their performance is straightforward and accurate.[14]

Horizontal elutriators have been used extensively as devices for measuring and collecting particles and as apparatae for a variety of aerosol experiments.[15-17] The British Medical Research Council adopted the penetration curve of a particular horizontal elutriator as the definition of respirable particles.[18] Mercer has reviewed many of the practical applications of elutriators for sampling respirable particles.[19] Hamilton and Walton[18] have established the criterion that reentrainment of deposited particles may occur if the ratio of the mean air velocity to duct height (rectangular geometry) reaches a critical value which lies between 240 and 650 sec^{-1}.

This paper describes the results of laboratory studies that were carried out to develop horizontal elutriators for measuring the IP concentration in fugitive, ambient, and stack aerosols. Specific designs were developed for use in conjunction with commercial, instack, cascade impactors, the EPA's Source Assessment Sampling System (SASS),[20] and the EPA's Fugitive Assessment Sampling Train (FAST).[21]

Background Discussion

The initial concept of the horizontal elutriator was the result of studies to measure quantitatively the deposition of aerosol particles on surfaces adjacent to aerosols flowing through laboratory apparatus. Natanson[22] and Thomas[23] independently solved this problem for particle settling in a circular, horizontal tube. Although the derivations are somewhat complex, the results can be summarized and simplified in terms of the collection efficiency (Eff) by the following equation:

$$\text{Eff} = \frac{2}{\pi}\left[2\varepsilon\sqrt{1-\varepsilon^{2/3}} \quad \varepsilon^{1/3}\sqrt{1-\varepsilon^{2/3}}\right] + \arcsin \varepsilon^{1/3} \qquad (1)$$

where

$\varepsilon = \dfrac{3V_s L}{8\ a\bar{V}}$ and .

V_s is the settling velocity,
L is the length of tube,
$\underline{a}$ is the radius of tube, and
$\bar{V}$ is the average velocity of the gas.

The theory describing the performance of a rectangular, flat-plate elutriator is considerably less complex and is re-derived here to give the reader a better understanding of the particle motion in the elutriator.

The settling velocity of spheres in a gas stream is given by the equation

$$V_s = \frac{C\rho g d^2}{18\eta} \qquad (2)$$

where

g is the acceleration due to gravity,
C is the slip correction factor,
ρ is the particle density,
d is the particle diameter, and
η is the viscosity of gas.

In health-related studies, the aerodynamic behavior of the particles is of interest. It is therefore convenient to relate the settling velocity of all particles, whatever their shape or density, to that of spheres having unit density. The aerodynamic diameter is defined as the diameter of a unit density sphere having the same settling velocity as the particle of interest. The aerodynamic diameter is given from Equation 2 by settling $\rho = 1$ g/cm³ (the units must be retained). Also, for particles larger than about 2 µm, the slip correction factor is approximately equal to unity. A graph of settling velocity vs. diameter is shown in Figure 4.

For fully developed flow between parallel plates, the velocity profile of a gas is parabolic with the maximum velocity equal to 3/2 the average and with zero velocity at the plates:

$$V_x = \left(\frac{6y}{h} - \frac{6y^2}{h^2} \right) \overline{V} \tag{3}$$

where

V_x is the velocity parallel to the plates, at a point y,
y is the displacement above the bottom plate,
h is the spacing between plates, and
$\overline{V}$ is the average velocity of the gas.

The velocity profile and a typical particle trajectory are illustrated in Figure 5.

The efficiency with which particles are collected is determined by the dimensions of the channel, the velocity of the gas, the setting velocity of the particles, and the height at which the particles enter the channel.

Consider a particle which enters the channel at position y_o as shown in Figure 6 and which has a trajectory of horizontal length L (the length of the channel). Neglecting diffusion, which is negligible for the particles of interest, all particles of this diameter or larger entering at or below position y_o will be captured. All particles of this diameter entering the channel at positions higher than y_o will penetrate the channel. Thus

$$\frac{dx}{dt} = \left(\frac{6y}{h} - \frac{6y^2}{h^2} \right) \overline{V} \ ;$$

but dy is given by $dy = V_s dt$, therefore

$$\int_o^L dx = \frac{\overline{V}}{V_s} \int_o^{y_o} \left(\frac{6y}{h} - \frac{6y^2}{h^2} \right) dy; \text{ and}$$

$$V_s L = \left(\frac{3y_o{}^2}{h} - \frac{2y_o{}^3}{h^2} \right) \overline{V} \ , \tag{4}$$

from which the length of the channel needed to capture particles of a particular diameter may be determined.

two filters and an extended, flared inlet was necessary to provide the desired velocity distribution. Figure 9 is a velocity profile measured using a thermal anemometer immediately upstream from the blower before the plates were in position. From these data, it was evident that the blower was pulling uniformly across the rectangular opening where the two 8 x 10 in. filters were positioned. Figure 10 shows the velocity profile measured upstream of the collector plates with the extended, flared inlet in position.

The velocity profiles shown in Figures 9 and 10 were considered satisfactory, and the overall average velocity was used to calculate the theoretical performance curves for the system. The average velocity through the chamber measured using the thermal anemometer was in agreement with previous calibration of the blower.

Two sets of experimental data were obtained from the testing of the horizontal elutriator. The first set was acquired while operating the settling chamber at an average gas velocity of 70 cm/sec and a plate length of 38.1 cm. The second data set was obtained by operating the system at 40 cm/sec after shortening the plate length to 20 cm. The theoretical curves of the collection efficiency versus aerodynamic particle diameter shown in Figures 11 and 12 were developed from Equation 5 using the following parameter values:

Figure 11	Figure 12
$\rho = 1.35$ g/cm^3	$\rho = 1.35$ g/cm^3
$g = 981$ cm/sec^2	$g = 981$ cm/sec^2
$L = 38.1$ cm	$L = 20$ cm
$\eta = 181 \times 10^6$ poise	$\eta = 181 \times 10^6$ poise
$\underline{h} = 0.701$ cm	$\underline{h} = 0.701$ cm
$\overline{V} = 70$ cm/sec	$\overline{V} = 40$ cm/sec
Reynolds No. = 315	Reynolds No. = 180
$\overline{V}/h = 100$	$\overline{V}/h = 57$

The calculated values from theory for the collection efficiency were found to be in excellent agreement with the measured values. No corrections were made for end effects.

The experiments described above indicated that the theoretical equations can be used to predict particle collection by horizontal elutriators to a high degree of accuracy. Consequently, the equations were used to create design nomographs for IP precollectors to be used in conjunction with the three systems of interest. Design parameters were calculated for horizontal elutriators to be used with: (1) cascade impactors operated at 14.2 ℓ/min and 149°C, (2) the Source Assessment Sampling System operated at 125 ℓ/min and 204°C, and (3) the Fugitive Assessment Sampling Train operated at 5,282 ℓ/min and 23°C.

Figures 13, 14, and 15 are the design nomographs for the three sampling devices. On the vertical axis is the open area required, neglecting the thickness of the tube walls. The horizontal axis is the length of the elutriator required to yield the IP performance at the specified flow rate and temperature. In constructing the graphs, it is assumed that the rectangular channels have widths much greater than their heights, so that the vertical walls will not have a significant effect on the gas flow.

Fugitive Assessment Sampling Train

The Fugitive Assessment Sampling Train (FAST), developed by TRC Environmental Consultants for EPA, was designed to obtain 500 milligram samples in an 8 hour period downwind of typical industrial sources. The initial prototype shown in Figures 16 and 17 consisted of a louvered inlet transform, a 15 μm D_{50} impactor precollector, a 2.5 μm D_{50} cyclone, and a back-up filter. The operating flowrate is 5.28 m^3/min. A 5 CFM side stream to an XAD-2 solid sorbent canister is used to measure the organic vapor content of the sampled gas stream.

Subsequent laboratory calibration of the precollection impactor by Southern Research Institute indicated that it was not operating properly; a large number of particles were bouncing and reentraining. The growing interest in the inhalable particulate fraction indicated that some type of 15 μm D_{50} precollector would still be necessary. The success that Southern had had in the laboratory evaluation of horizontal elutriators led to the decision to design a 15 μm D_{50} horizontal elutriator inlet collector for the FAST. Knowing the flowrate of the FAST and the size and weight limitations required by TRC it was a straightforward calculation to determine the specifications for the inlet elutriators.

The final design was for a horizontal elutriator consisting of 67 slots of height 7 mm, and a slot width of 45 cm and length of 21.5 cm. In order to facilitate removal and cleaning of the elutriator section after each test, the plates are mounted in two removal containers as shown in Figure 18. Alignment pins in each container hold the 67 plates in position. Slide type covers can be inserted to close off the elutriator section before and after sampling to prevent contamination. See Figures 19, 20, and 21. The elutriator is mounted in front of the FAST as shown in Figures 22 and 23.

After the elutriator was built, it was shipped to Southern Research Institute for calibration tests. The laboratory set up was as shown in Figure 24. Monodisperse 15 μm and 16 μm aerodynamic diameter particles of ammonium fluorescein were sampled. The particle generator outlet was moved across the louvered inlet section to simulate a uniform inlet aerosol concentration during the sampling period. The particle collection efficiency for these two particle sizes was 47.8% and 58.8%, respectively as shown in Table 1. Figure 25 shows these data points along with the theoretical efficiency curve. The agreement between theory and experiment is very good.

The new Fugitive Assessment Sampling Train is now awaiting its initial field sampling test which should occur during the summer of 1980.

Summary

Horizontal elutriation has been shown to be an effective and accurate method for obtaining inhalable particulate samples. Application of the horizontal elutriator method to the Fugitive Assessment Sampling Train has proven the design extrapolation to a full scale device. Future field tests will determine the usefulness of horizontal elutriation under actual industrial operating environments.

TABLE 1

FAST HORIZONTAL ELUTRIATOR INLET TEST DATA

Test No.	1	2
Aerodynamic Particle Diameter (μm)	16.0	15.0
Filter Pressure Drop ("Hg)	2.0	2.2
Sampling Duration (hrs.)	4	2.5

	% of Total Mass	% Coll. Eff.	% of Total Mass	% Coll. Eff.
Inlet Louvre Section	0.75*	0.75	28.2	28.1
Screen	0.0009*	0.0009	5.34	8.4
Screen to Elutriator Transform	3.63	3.65	1.56	2.4
Elutriator Plates	56.2	58.8	31.2	47.8
Plate Holder Section	0.5	1.27	0.14	0.4
Filter Transform and Filter	38.9	100.0	33.7	100.0

*Questionable results due to inaccurate washing technique.

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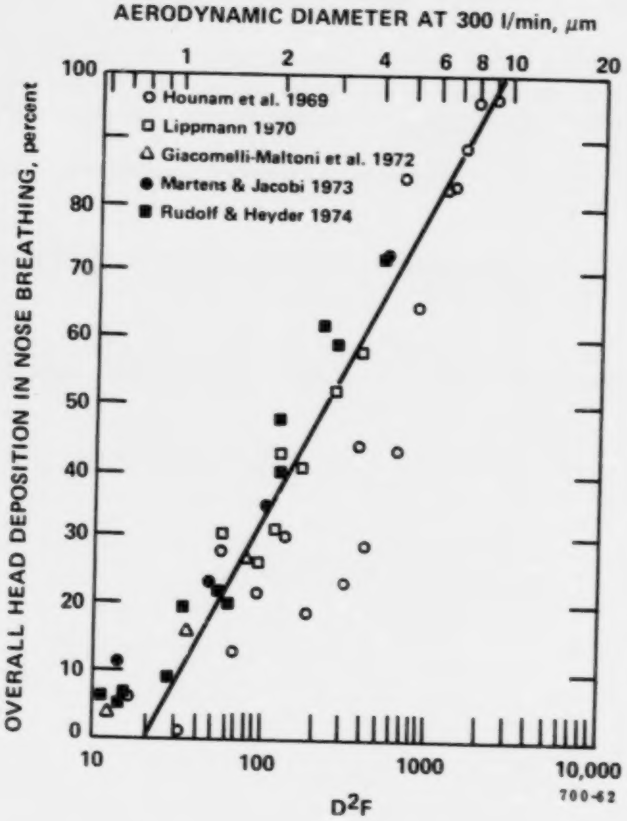

Figure 1. Deposition of monodisperse aerosols in the head during inhalation via the nose versus D^2F, where D is the aerodynamic equivalent diameter (μm) and F is the average inspiratory flow (l/min).[2-6] The inspiratory flows in the individual studies of this composite range from 5 to 60 l/min. The heavy solid line is the International Commission of Radiological Protection Task Group[7] deposition model.

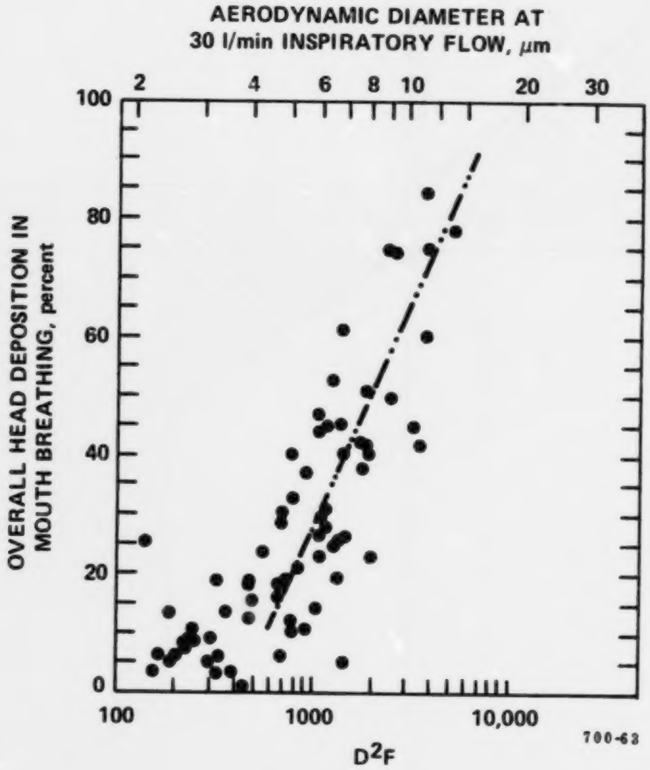

Figure 2. Deposition of monodisperse ferric oxide aerosol in the heads of nonsmoking healthy males during mouthpiece inhalations as a function of D^2F where D is the aerodynamic equivalent diameter (μm) and F is the average inspiratory flow in liters/min. An eye-fit line describes the median deposition between 10 and 80%.[7] The fitted line has been extrapolated to 15 μm.

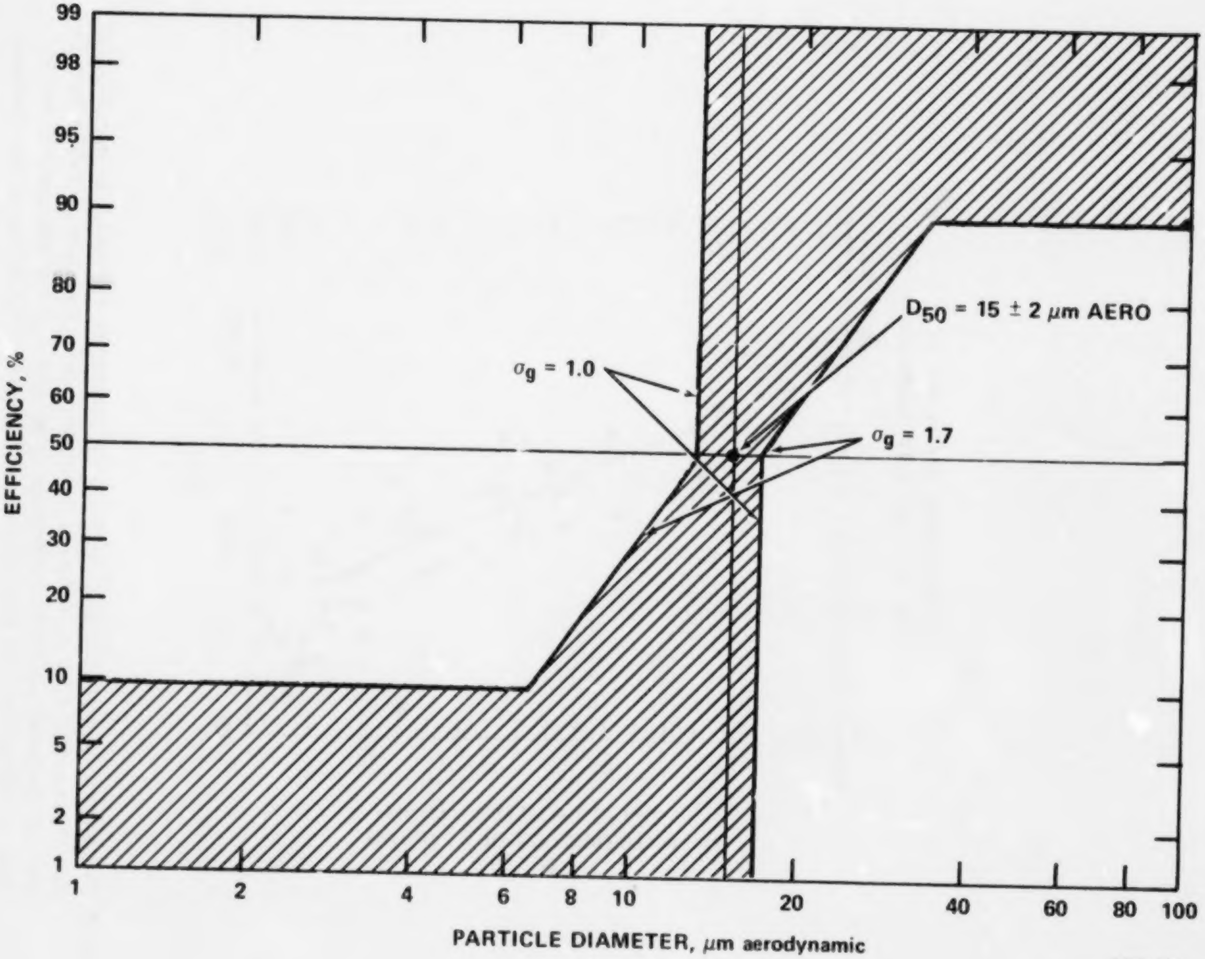

Figure 3. Recommended specifications for collection efficiency of samples of inhalable particulate matter.

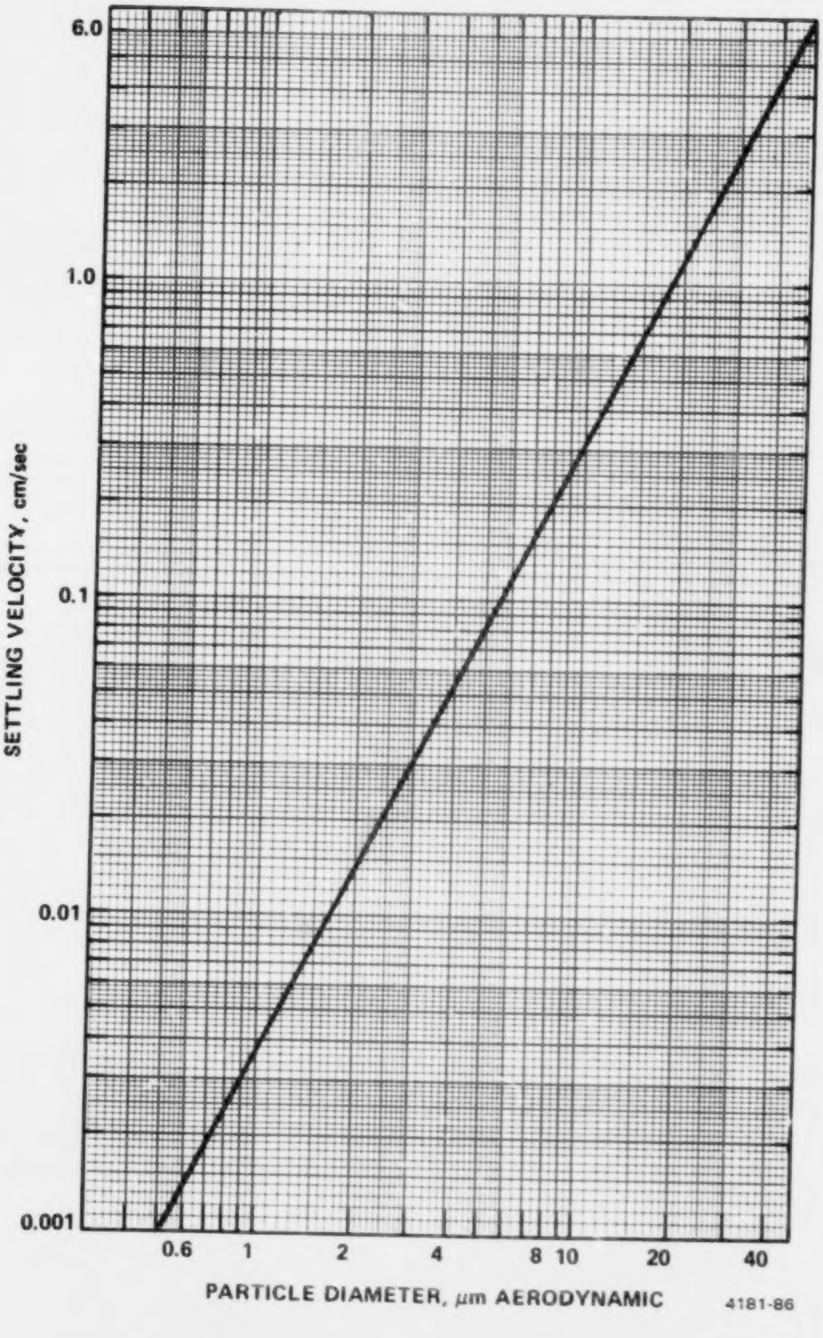

Figure 4. Settling velocity in air for unit density spheres.

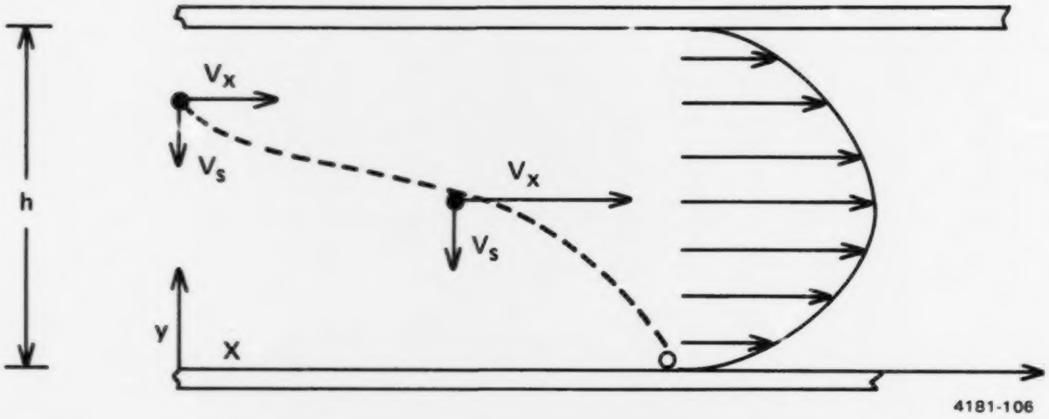
h
V_x
V_s
V_x
V_s
y
X
4181-106

Figure 5. Velocity profile and particle trajectory between parallel plates.

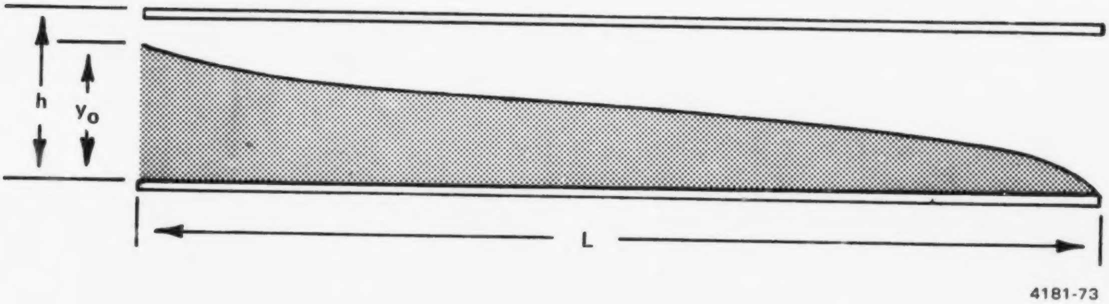
h
y_o
L
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Figure 6. Zone of 100% particle collection.

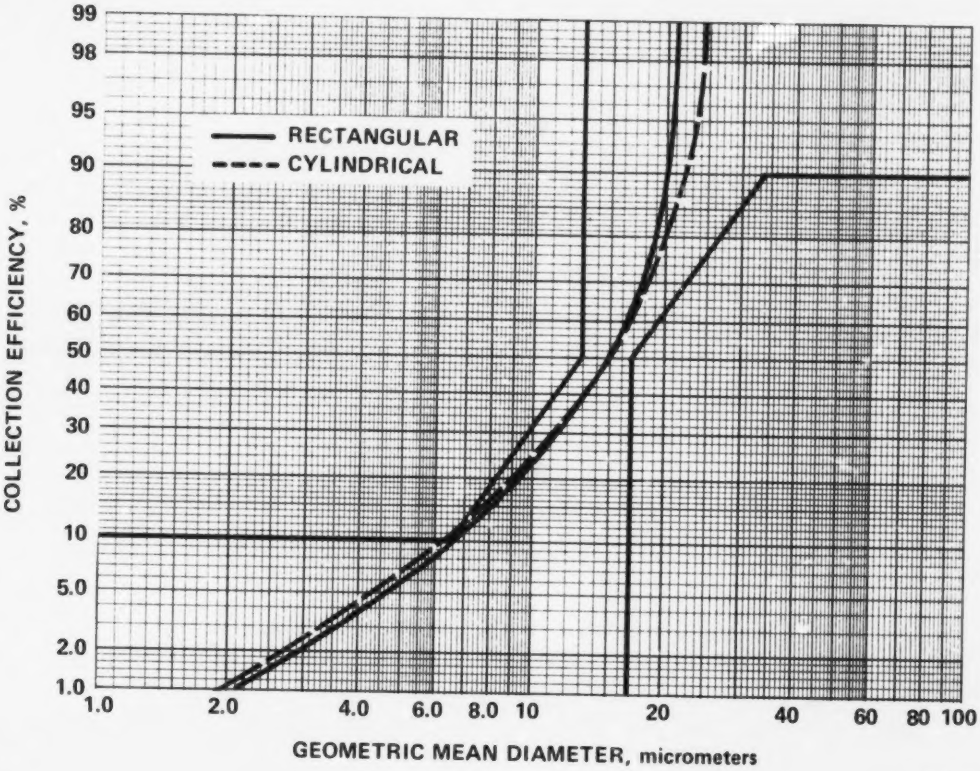

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Figure 7. Theoretical collection efficiency by particle settling in rectangular and cylindrical tubes.

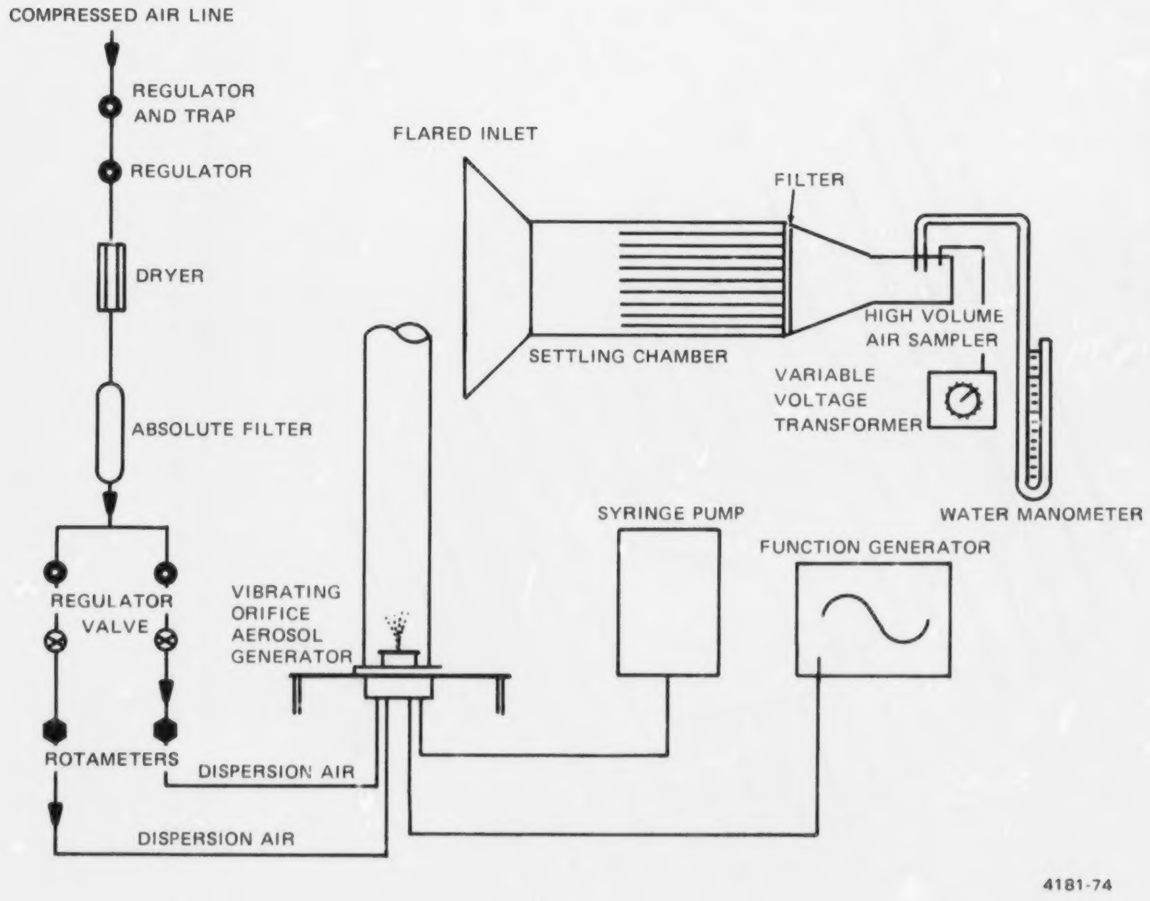
COMPRESSED AIR LINE
REGULATOR AND TRAP
REGULATOR
DRYER
ABSOLUTE FILTER
REGULATOR
VALVE
ROTAMETERS
DISPERSION AIR
DISPERSION AIR
VIBRATING ORIFICE AEROSOL GENERATOR
FLARED INLET
SETTLING CHAMBER
FILTER
HIGH VOLUME AIR SAMPLER
VARIABLE VOLTAGE TRANSFORMER
WATER MANOMETER
SYRINGE PUMP
FUNCTION GENERATOR
4181-74

Figure 8. Apparatus used to measure the collection efficiency of the settling chamber.

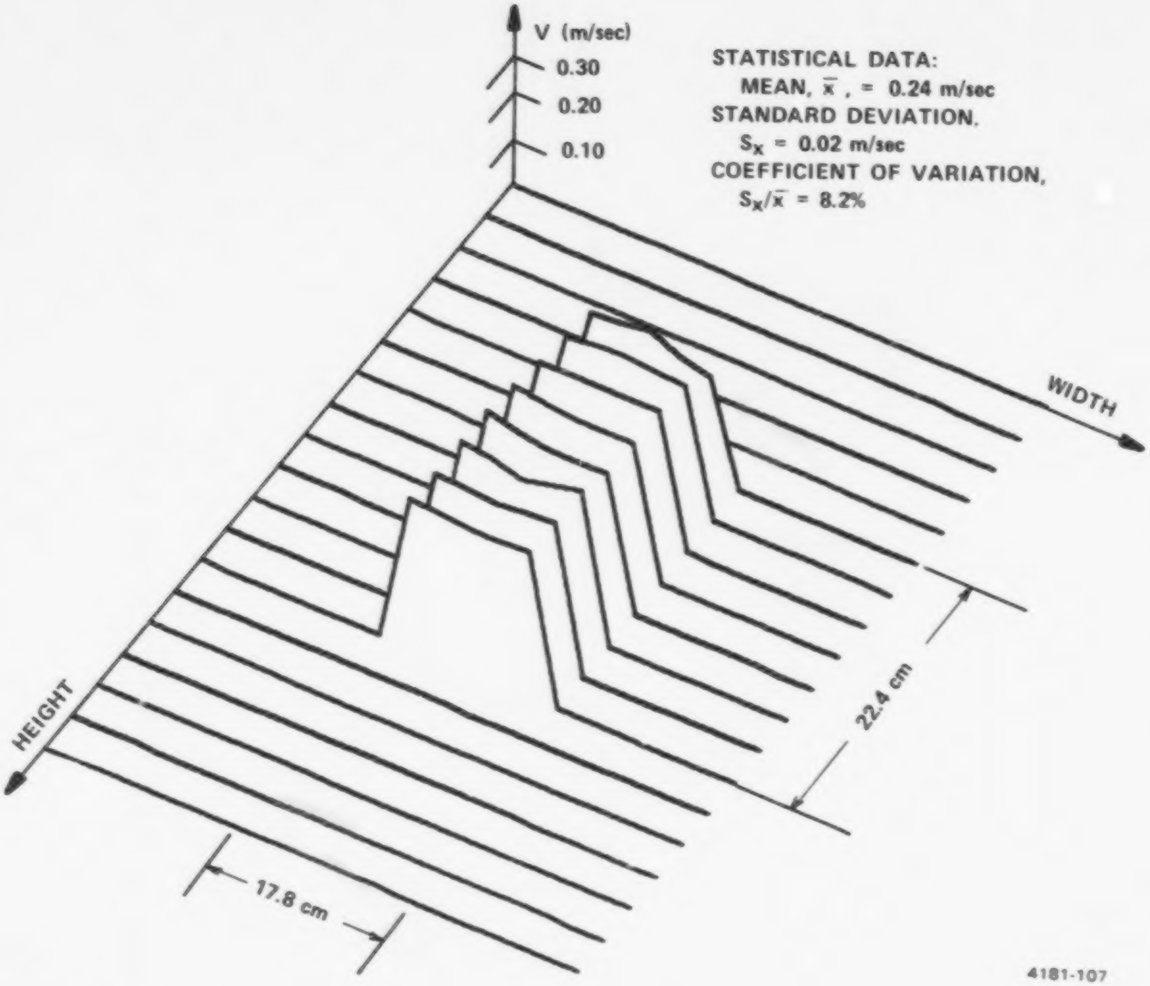

Figure 9. Profile of the air velocity immediately upstream from the blower of the settling chamber before the plates were positioned.

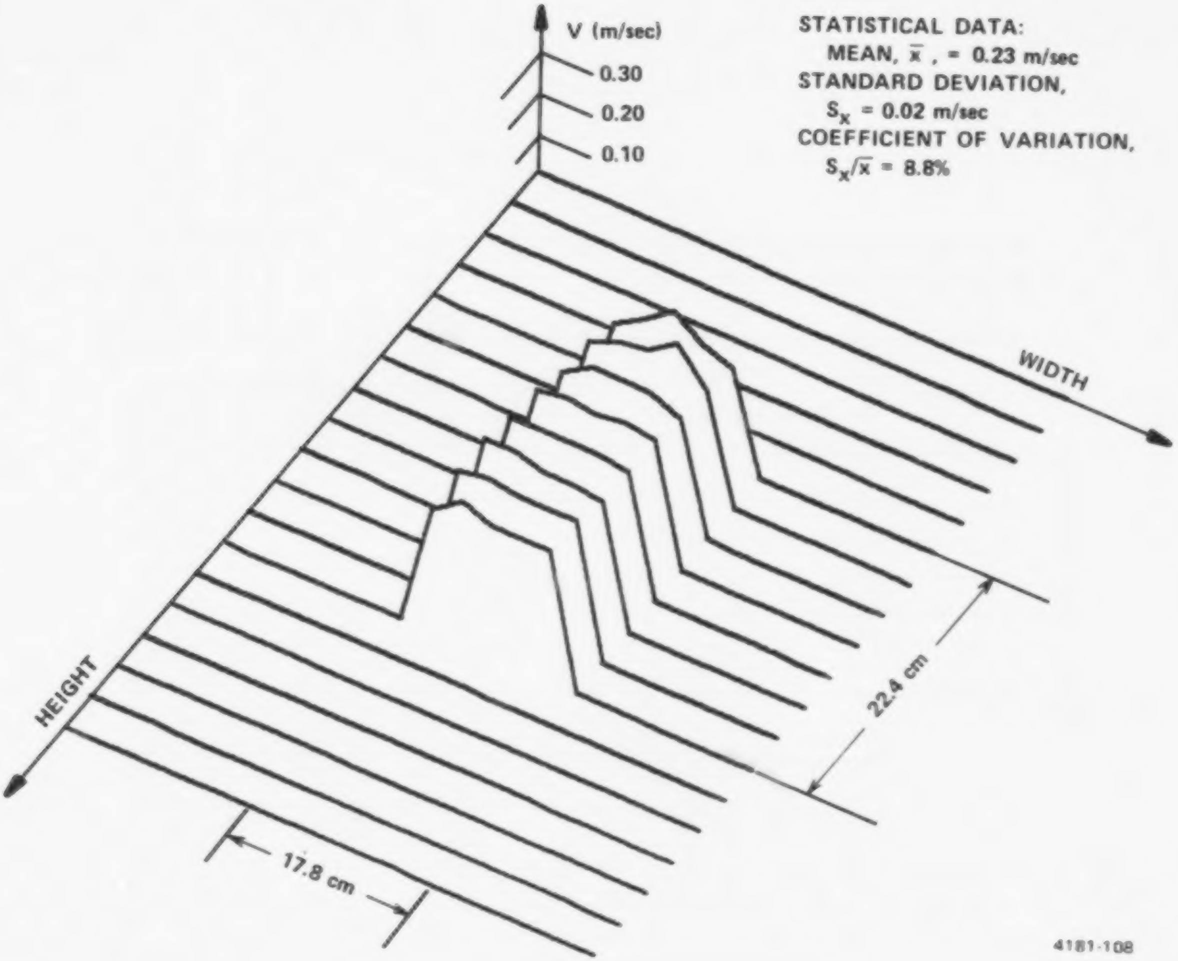

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Figure 10. Profile of the air velocity upstream from the plates of the settling chamber.

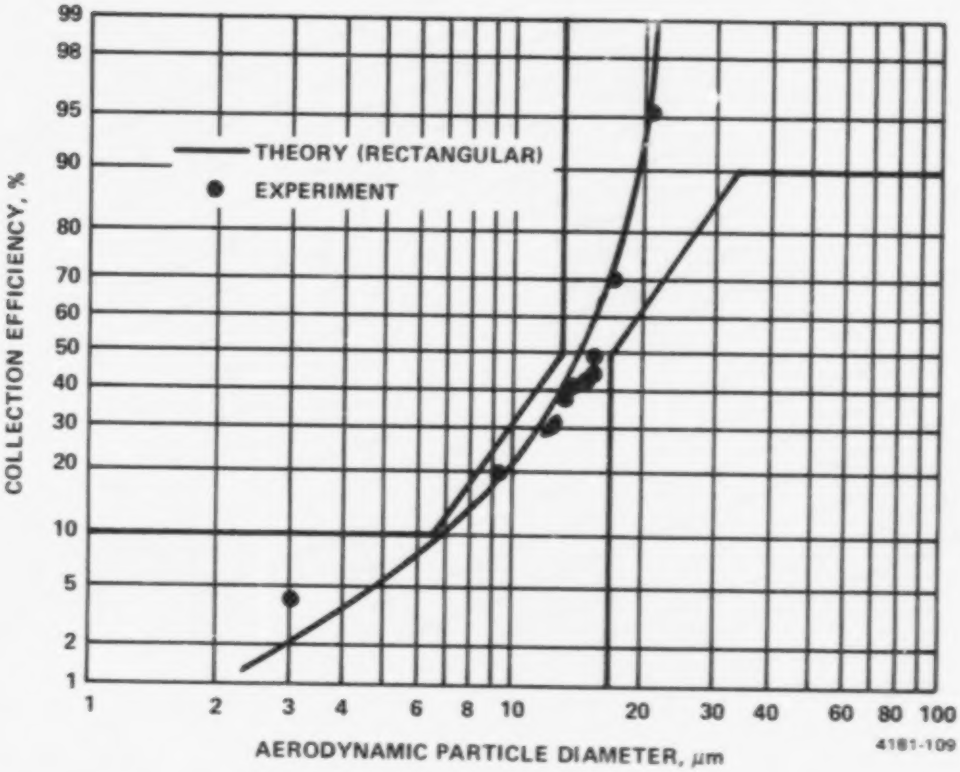

Figure 11. Collection efficiency vs. aerodynamic particle diameter for the horizontal elutriator. Length = 38.1 cm.

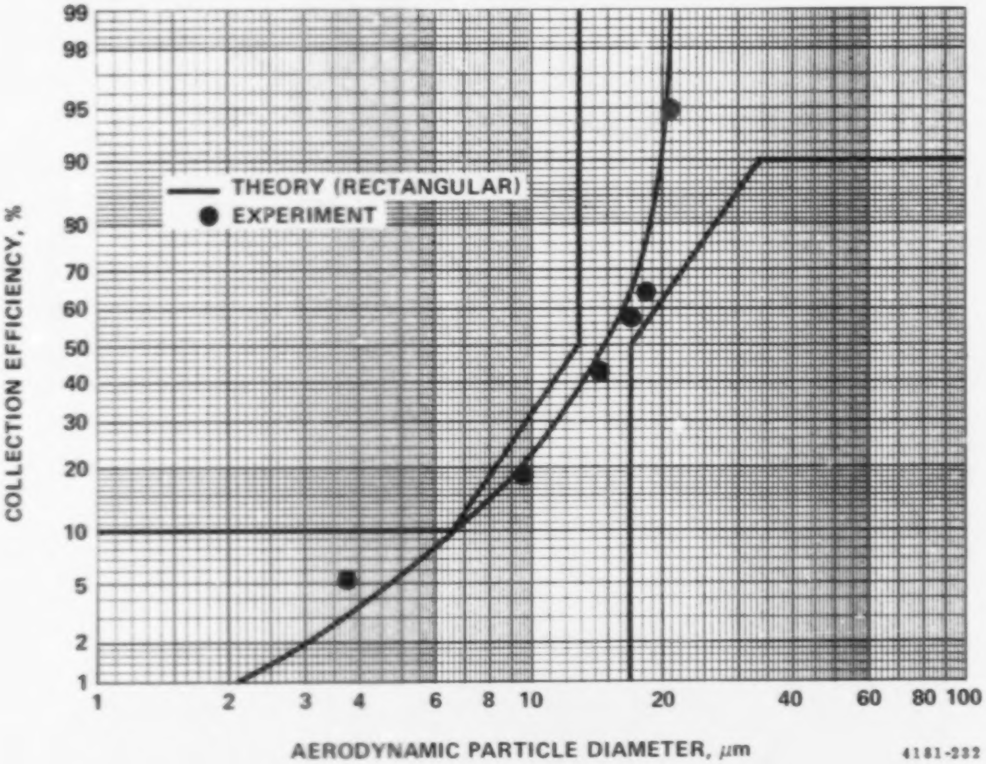

Figure 12. Collection efficiency vs. aerodynamic diameter for the horizontal elutriator. Length = 20 cm.

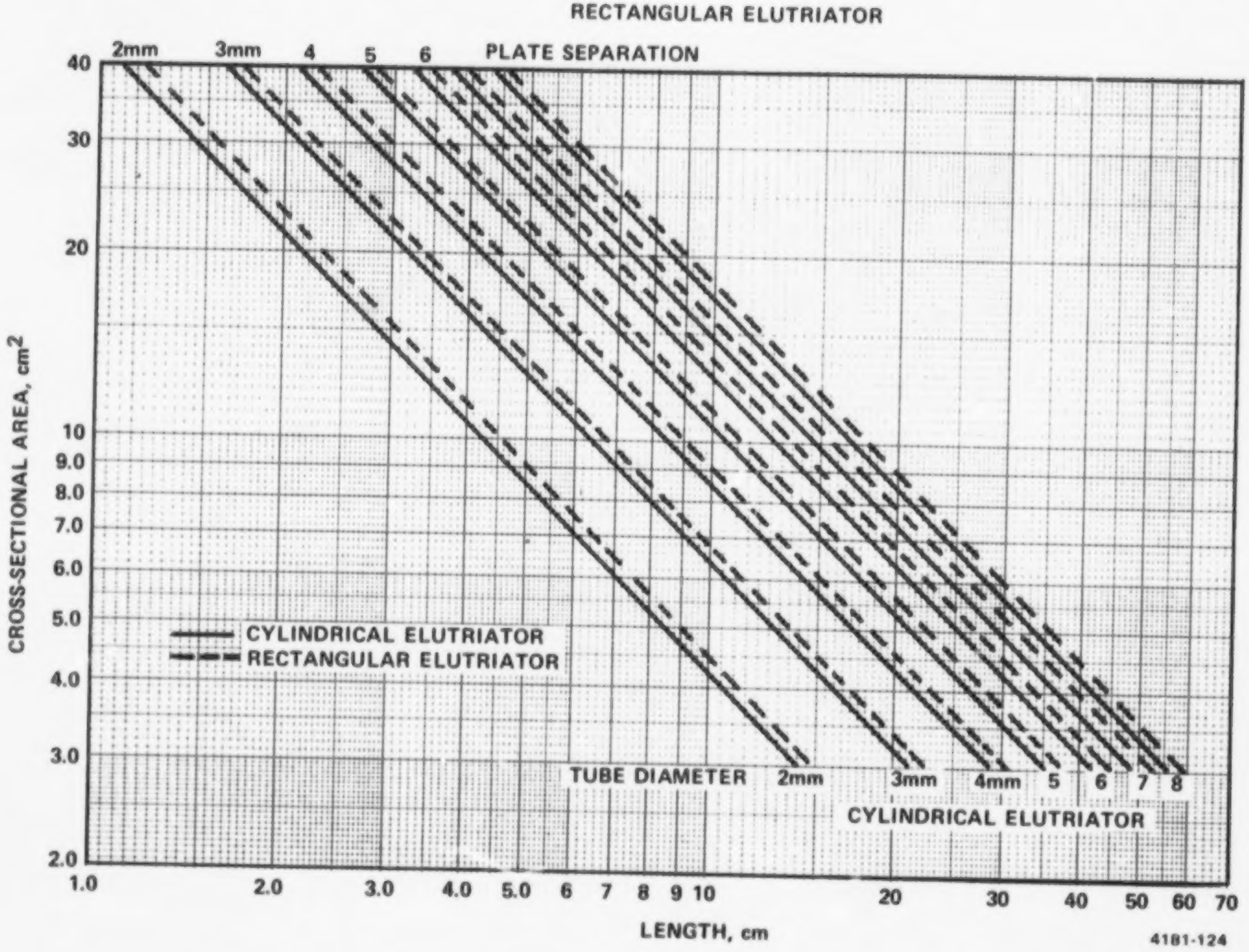

Figure 13. *Relationship of design parameters for horizontal elutriators with D_{50} cutpoints of 15 μm aerodynamic diameter used as precollectors for instack cascade impactors.*

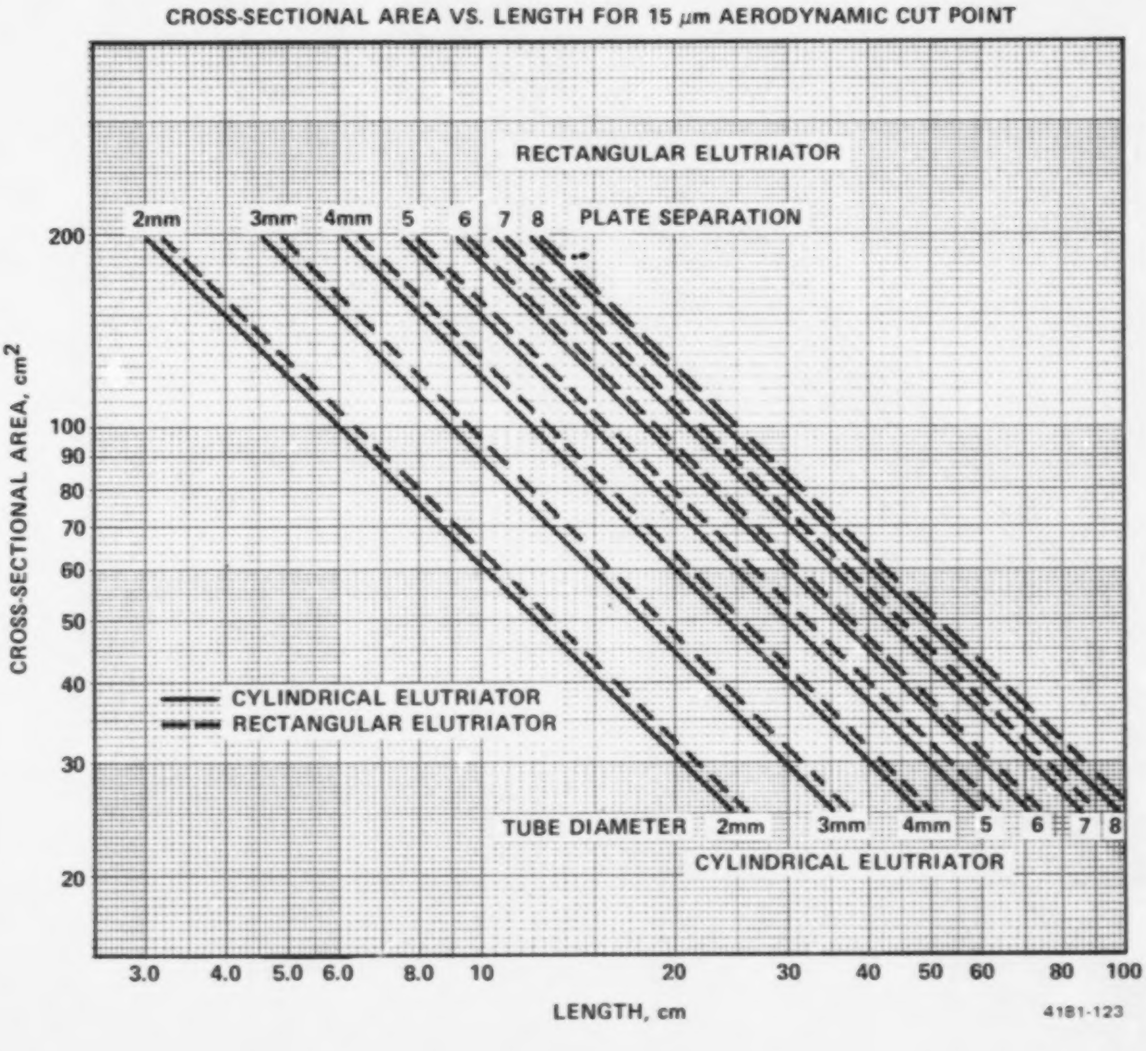

Figure 14. Relationship of design parameters for horizontal elutriators with D_{50} cutpoints of 15 μm aerodynamic - SASS.

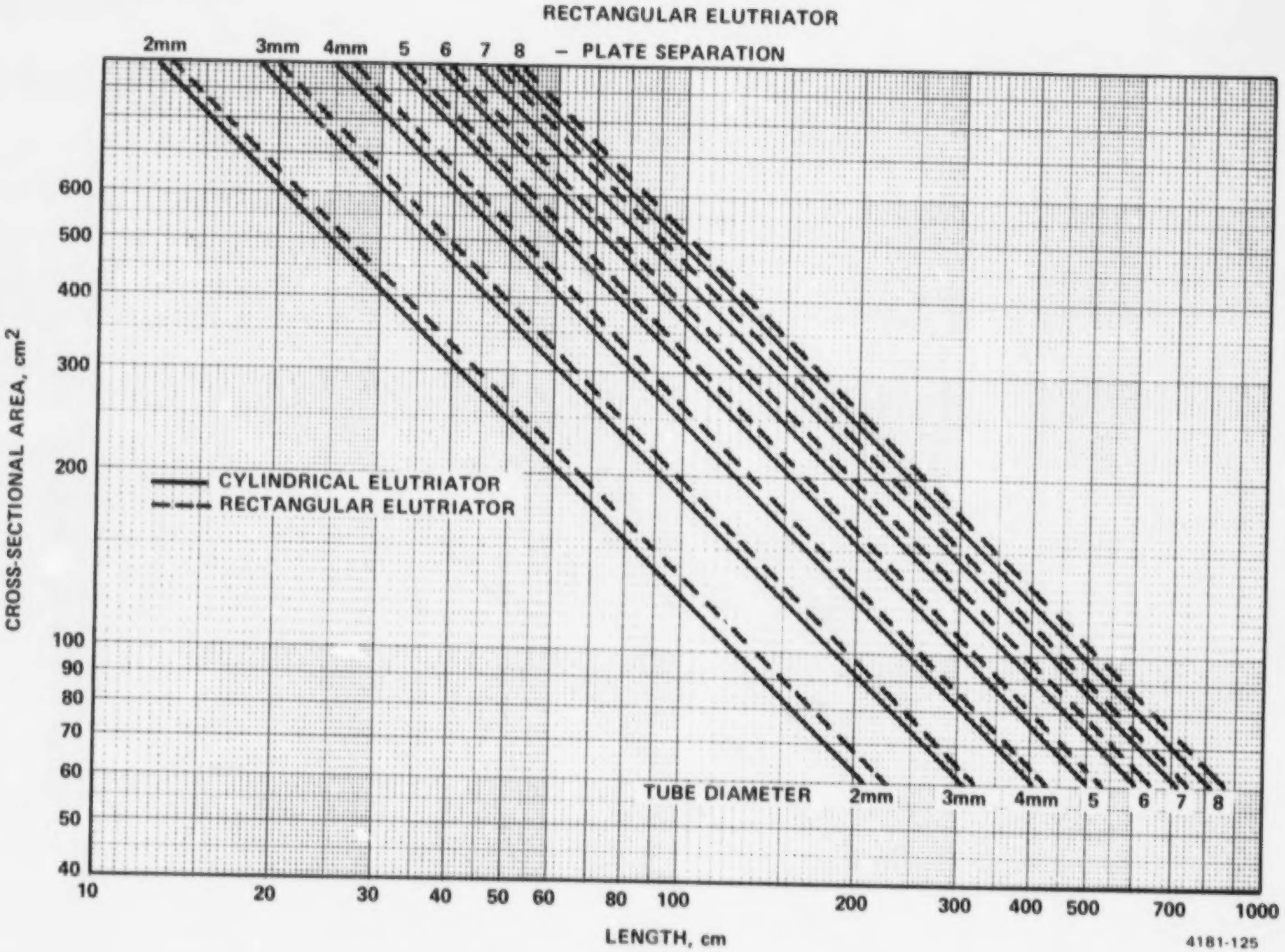

Figure 15. Relationship of design parameters for horizontal elutriators with D_{50} cutpoints of 15 µm aerodynamic diameter - FAST.

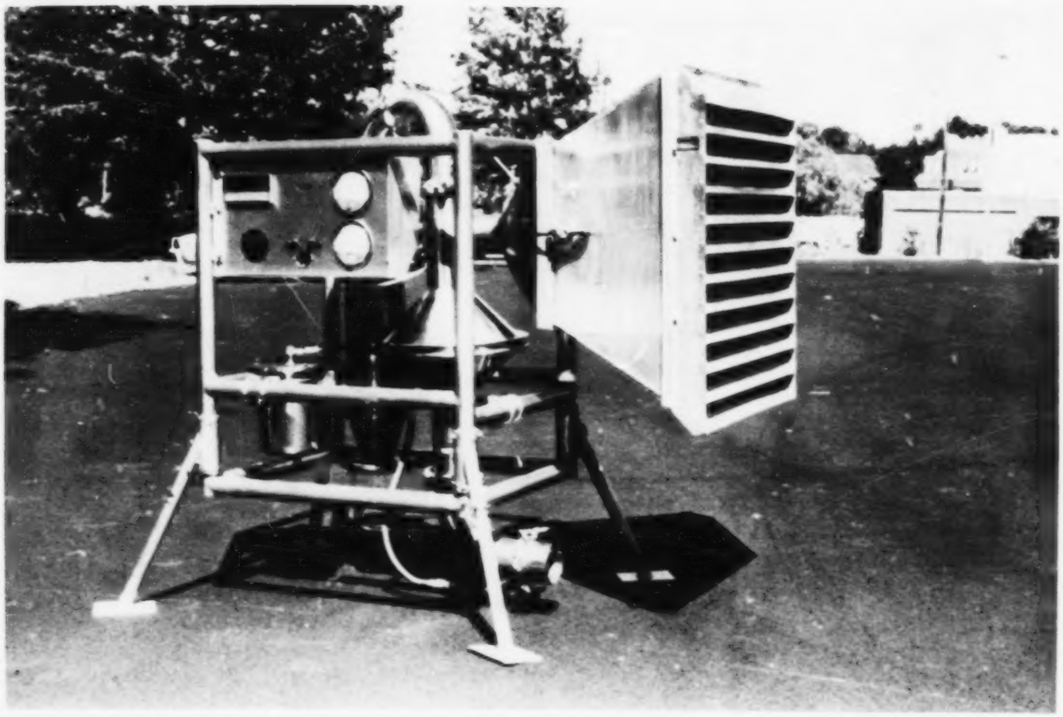

Figure 16. Fugitive assessment sampling train with cascade impactor precollector.

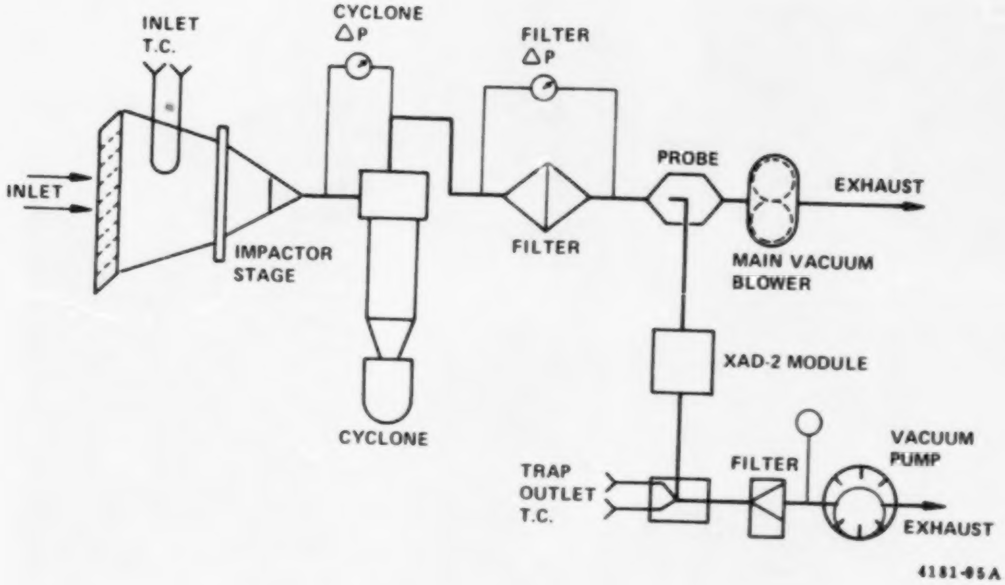
INLET
T.C.
CYCLONE
ΔP
FILTER
ΔP
INLET
PROBE
EXHAUST
IMPACTOR
STAGE
FILTER
MAIN VACUUM
BLOWER
XAD-2 MODULE
CYCLONE
TRAP
OUTLET
T.C.
FILTER
VACUUM
PUMP
EXHAUST
4181-05A

Figure 17. Fugitive Assessment Sampling Train components.

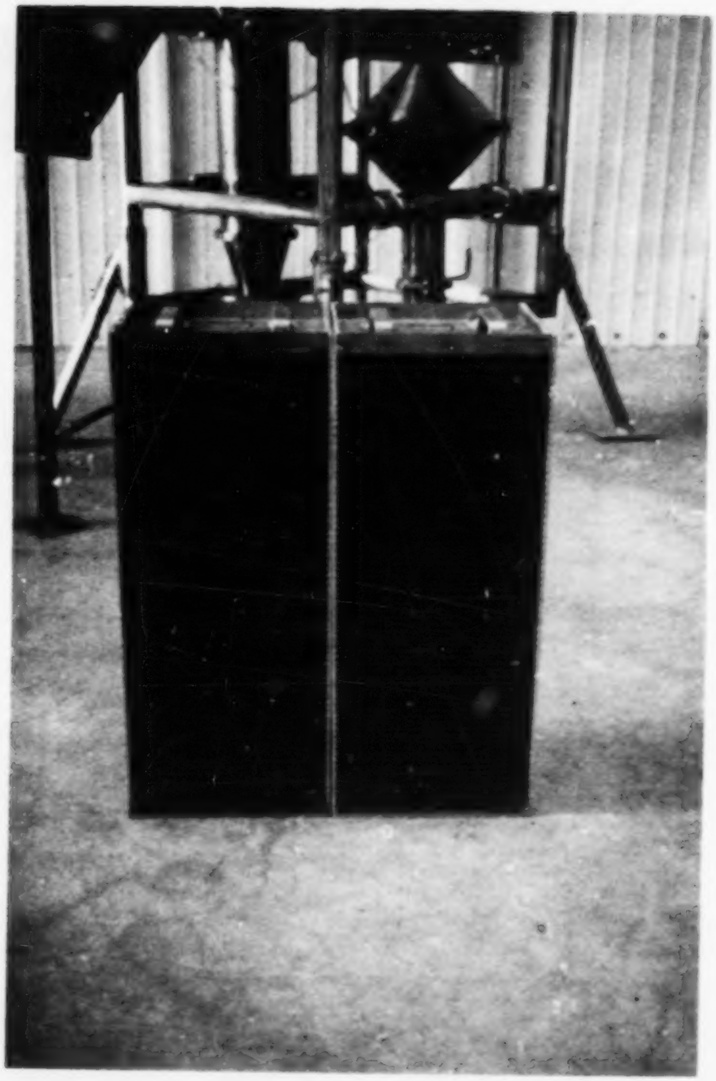

Figure 18. Horizontal elutriator container for FAST.

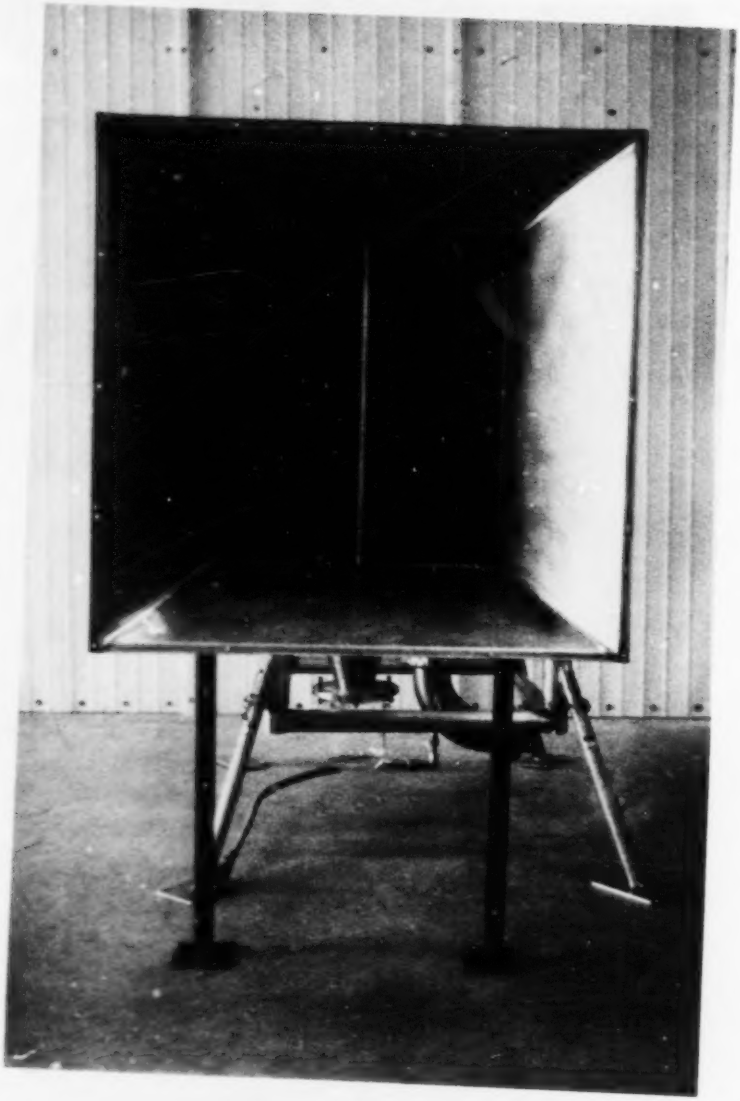

Figure 19. Horizontal elutriator positioned downstream of inlet transform.

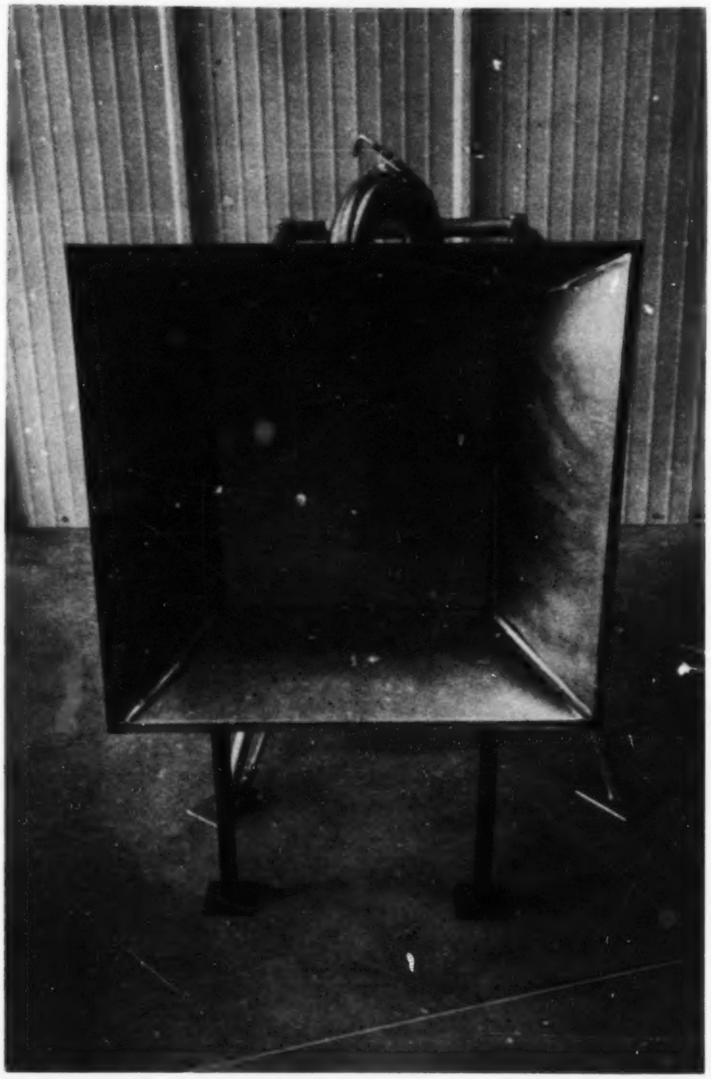

Figure 20. Slide covers protecting FAST horizontal elutriator.

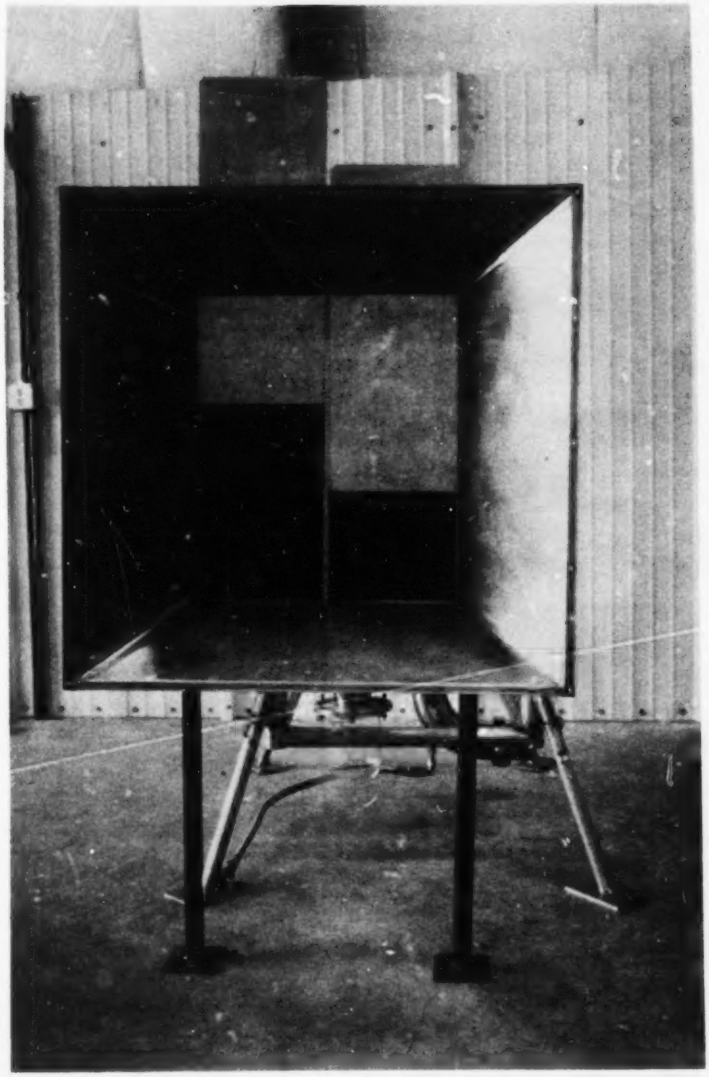

Figure 21. Slide covers of FAST horizontal elutriator partially removed.

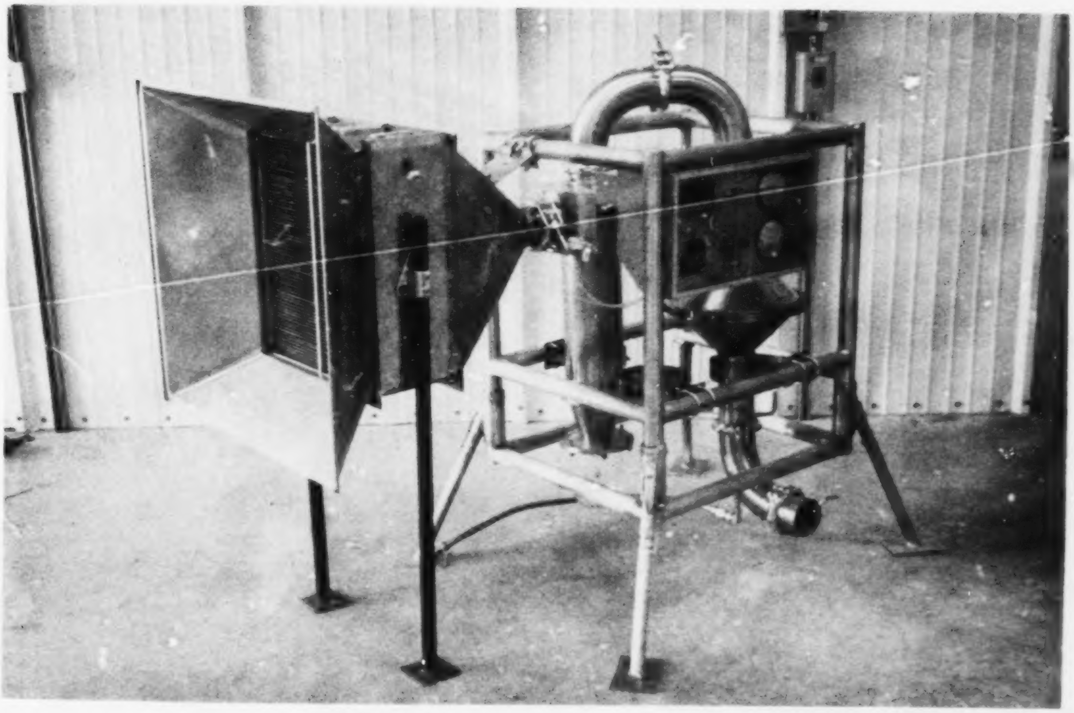

Figure 22. Horizontal elutriator positioned on inlet of FAST.

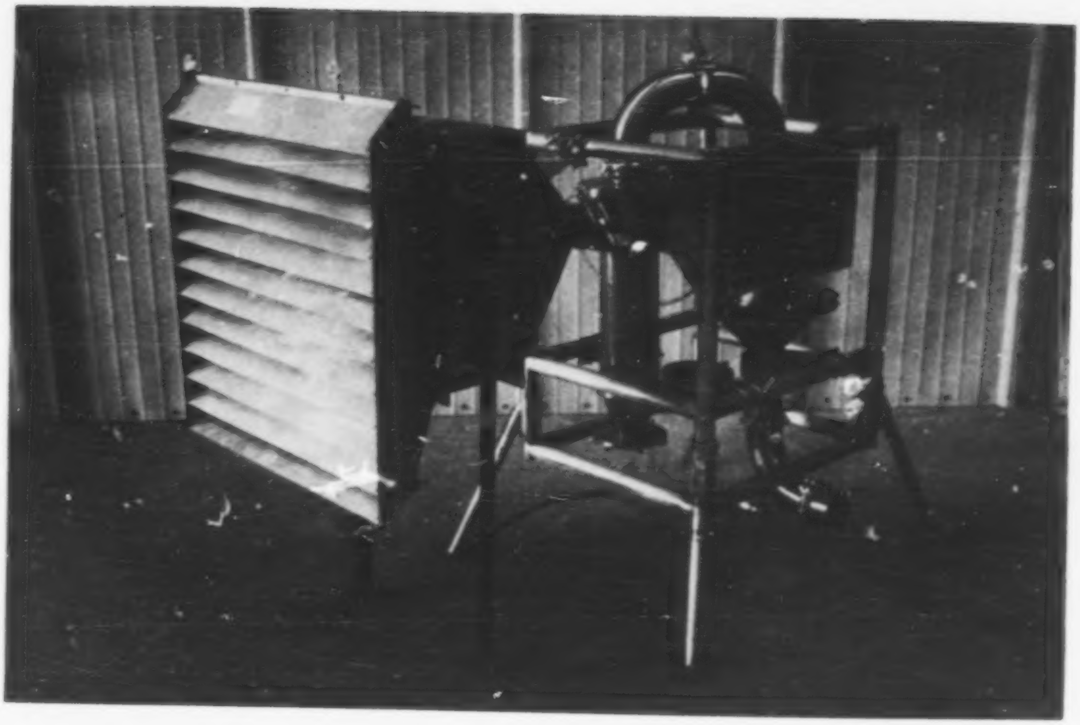

Figure 23. Louvered inlet positioned on front of FAST.

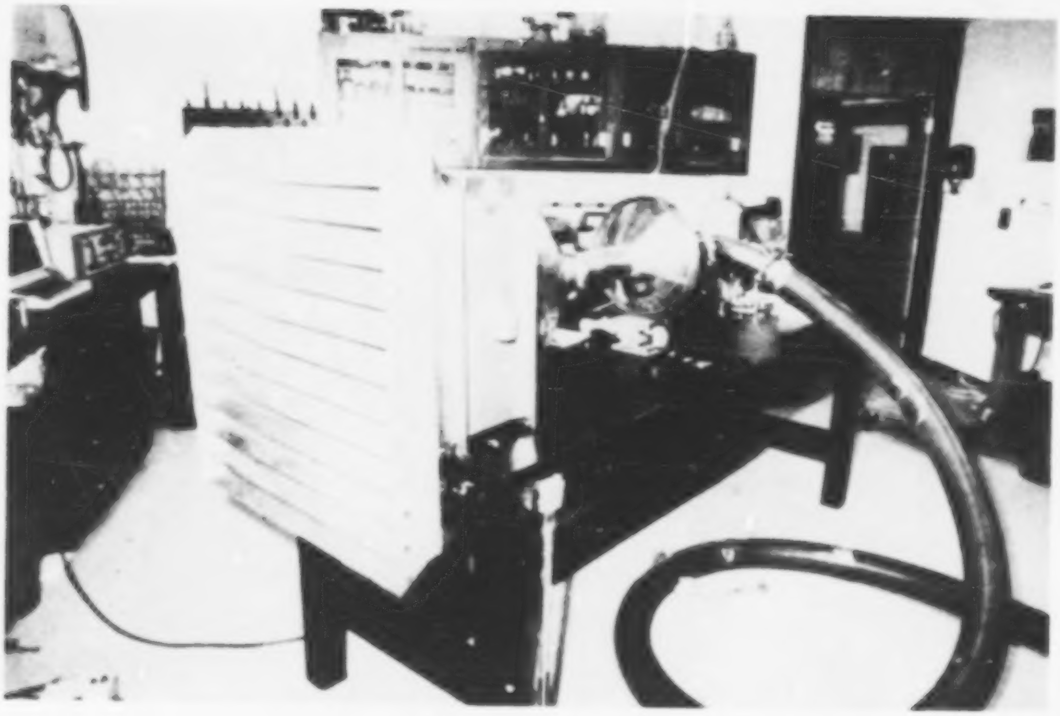

Figure 24. Laboratory set-up for calibration of FAST horizontal elutriator.

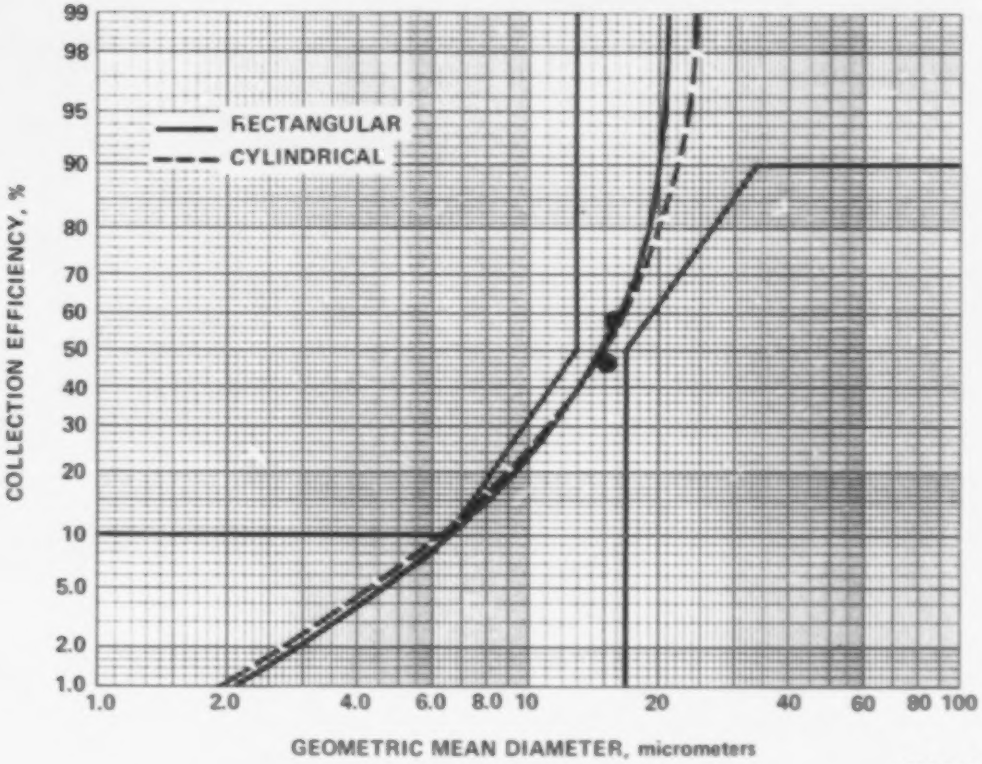

Figure 25. *Laboratory calibration data for the FAST horizontal elutriator inlet collector. Also shown are theoretical collection efficiency curves for rectangular and cylindrical tubes.*

TECHNIQUES FOR EVALUATING SURFACE AND GROUND WATER EFFECTS OF DRY ASH DISPOSAL

by

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ABSTRACT

Utilities are finding it necessary to switch to dry fly ash handling to minimize water quality impacts. At the same time, regulations regarding solid waste disposal are becoming increasingly more stringent. In switching from a wet sluiced system to dry ash disposal at the Montour Steam Electric Station, Pennsylvania Power and Light Company required data as to the surface and ground water effects of ash disposal for both design and permit purposes. To provide these a study program of laboratory testing and computer modeling was conducted in conjunction with a detailed site investigation.

Three types of laboratory testing were involved. They included: an extraction leachate test to assess ash variability; a serial batchwise extraction test to determine ash leachate quality and potential ground water effects; and a runoff simulation. To determine runoff quality the simulation results were then used as input into a modified version of EPA's SSWMM computer model.

The paper will discuss the testing techniques and how the program results were incorporated into the disposal site design and plan of operations.

INTRODUCTION

Pennsylvania Power & Light Company (PP&L) operates a 1500-megawatt coal-fired (eastern bituminous) steam electric generating station (the Montour Station) near Washingtonville, Montour County, Pennsylvania. In 1976 PP&L was cited by the state environmental agency for discharging arsenic at levels which caused the water quality criteria of the station's receiving stream to be exceeded. An investigation by the company revealed that most of the arsenic was being released from the fly ash as a result of the wet sluicing and ponding process. Attempts to identify the mechanisms controlling the arsenic levels in the ash pond were largely unsuccessful, and so after evaluating various other alternatives (waste recycle, discharge relocation, and stream augmentation) the company decided to convert the existing wet ash handling system to a dry system.

This meant that any ash which could not be immediately marketed for reuse would have to be landfilled. After considering twelve possible sites, a 170-acre company-owned tract adjacent to the station was finally selected as having the least potential environmental impact after development (Figure 1). To determine just what this impact would be and how best to minimize it, a study of the ash and site characteristics was undertaken. Of greatest concern were the effects the ash leachate and runoff might have on local ground water supplies and area streams. What was being sought ultimately was a basic landfill design concept and plan of operations.

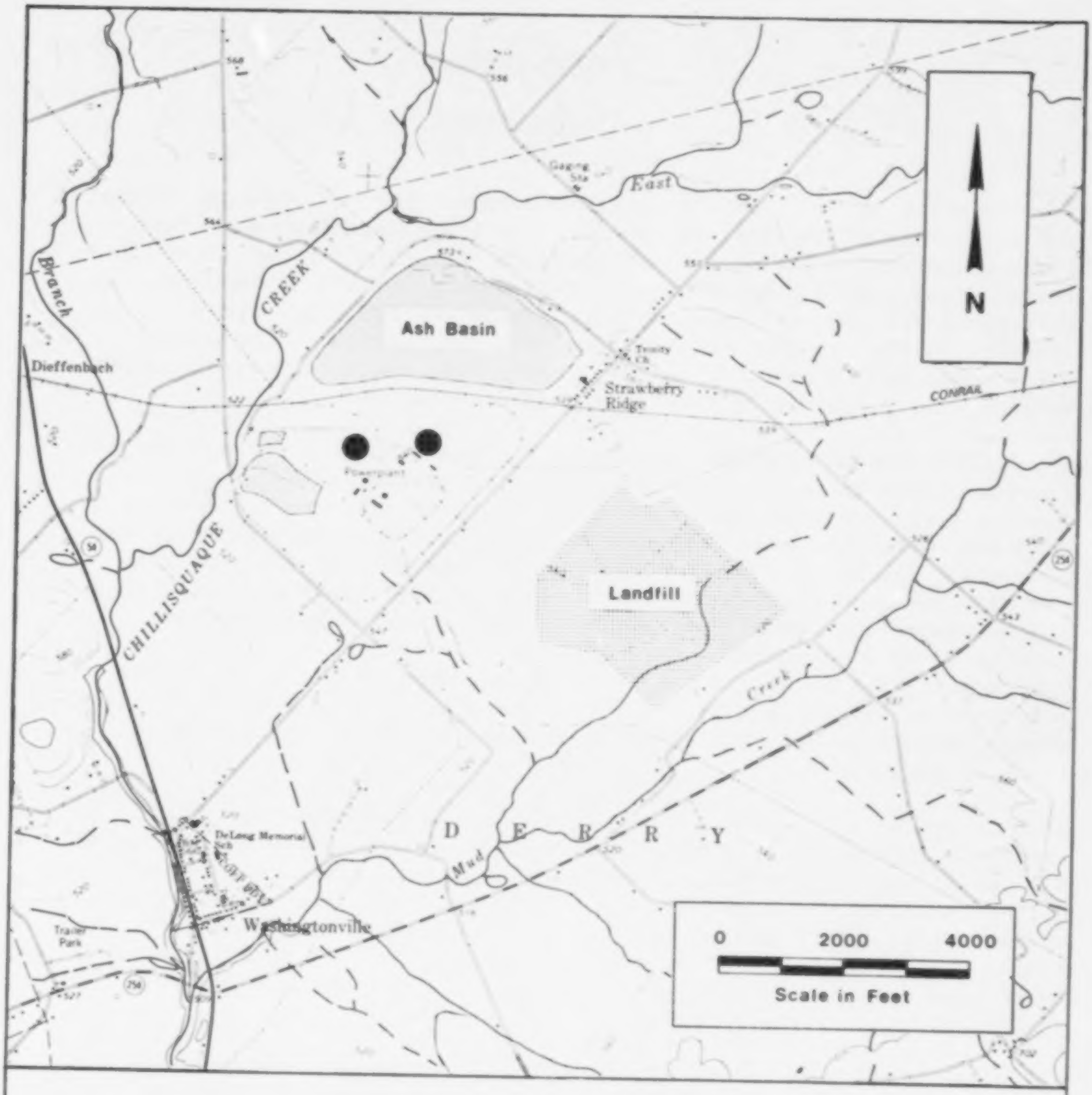
Ash Basin
Landfill
N
0
2000
4000
Scale in Feet
East
Branch
CREEK
CHILLISQUAQUE
Dieffenbach
Trinity Ch
Strawberry Ridge
CONRAIL
Powerplant
DeLong Memorial Sch
Washingtonville
Trailer Park
D E R R Y
Mud
Creek

FIGURE 1
PLOT PLAN

STUDY PROGRAM

Ash Variability

The variation in ash chemistry was investigated for two reasons. First, the full range of chemical variability had to be established so that representative samples of the ash could be collected for the later leaching and runoff simulations. It was also necessary to know just how this range fit into the possibly larger range of ash types likely to be produced by the station over time, so that the results of the present study would have some applicability beyond just the immediate situation. Several likely sources of variation were considered.

Generally speaking, fly ash represents the non-combustible fraction of the coal being burned. Thus, the chemical characteristics of the fly ash are largely determined by the composition of this non-combustible fraction, which can vary from coal to coal, even for coals from the same mine (1). The Montour Station receives the majority of its coal from two supplies in western Pennsylvania, one a captive deep mine working a single seam ("Greenwich" coal) and the other a stripping operation working up to five separate seams ("Benjamin" coal). The proportion of coal coming from each is about 2:1 Greenwich:Benjamin. To the extent possible the fly ash samples collected for the study were keyed to these two supplies in an attempt to control this one important source of chemical variation.

Once in the boiler, where the fly ash is actually formed, the coal is subjected to various operating conditions which could also contribute to ash variability. They include combustion temperature, excess oxygen, and station load. Rather than try to isolate each source of variation, the extent to which these operating conditions might be expected to change was quickly checked by reviewing past station operating records. In no case was the change found to be significant enough to warrant further detailed investigation.

After its production in the boiler, the fly ash is exhausted through the station's electrostatic precipitators, where it is removed from the combustion gases and then transferred to a series of hoppers for collection (32 for each generating unit arranged in two banks of 16, as shown in Figure 2). From work done earlier at the station it was known that the smaller ash particles tended to be concentrated in the outlet hoppers (those furthest from the boiler) and the larger size fraction in the inlet hoppers (those closest to the boiler). Since the partitioning of chemical elements by ash particle size is well documented in the literature (2, 3, 4, 5), most of the effort to quantify the chemical variability of the ash was concentrated in this area.

The principal technique used to evaluate the effects of size sorting on ash chemistry was to take a sample of ash from an inlet, outlet, or mid-range hopper, add it to distilled water at a low solid:liquid ratio (50

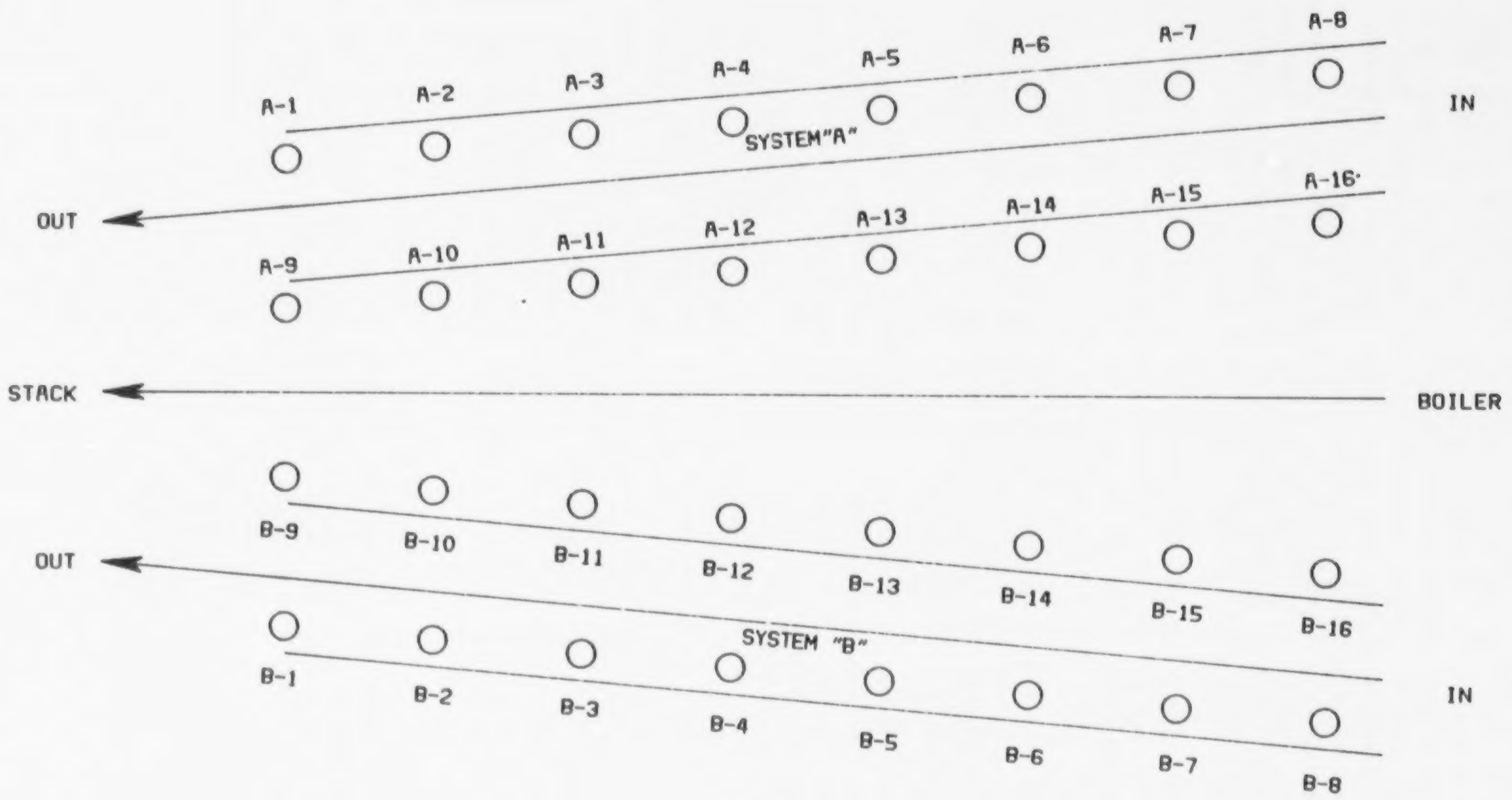
A-1
A-2
A-3
A-4
A-5
A-6
A-7
A-8
IN
SYSTEM"A"
OUT
A-9
A-10
A-11
A-12
A-13
A-14
A-15
A-16
STACK
BOILER
B-9
B-10
B-11
B-12
B-13
B-14
B-15
B-16
OUT
SYSTEM "B"
IN
B-1
B-2
B-3
B-4
B-5
B-6
B-7
B-8

FIGURE 2
FLY ASH HOPPER LAYOUT

g:800 ml), mix for 10 minutes, let the mixture stand for an hour, and then decant and filter. The parameters were standardized for each test run so as not to introduce any new variables into the system. The mixing time selected was determined by separate test and represents a stable condition characterized by constant pH and conductivity. The low solid:liquid ratio was designed to prevent suppression of one dissolved species by another more soluble species ("first ion effect"). The results of the analyses performed on the resulting solutions are presented in Tables 1 and 2. As a gross check on these results samples of the ash itself were also analyzed by atomic absorption and emission spectrographic methods. The results of these analyses are presented in Table 3.

This data clearly shows that the Greenwich and Benjamin ashes produce very different aqueous solutions. In particular, the Greenwich ashes are generally strongly alkaline (pH 10-11), have a high calcium:iron ratio (characteristic of the strong alkalinity (6)), and contain no detectable manganese or nickel. The Benjamin ashes, on the other hand, are strongly acidic (pH 3-4) and have a low calcium:iron ratio. This large difference in pH is significant because it indicates that any future changes in ash chemistry will probably fall within the range of characteristics already studied.

The data also shows a marked variation in ash chemistry with particle size sorting, as evidenced particularly by the increasing concentrations of arsenic, selenium, and chromium in the extracts from the hopper samples collected at increasing distances from the boiler. Thus, ash samples from the outlet hoppers could be expected to produce "worst case" solutions having the highest dissolved metals concentrations. This was important to know as far as planning future sampling activities. The data from the first phase of the study also served to identify which chemical elements would most likely be leached out of the ash in large amounts (the potential "bad actors") and which in insignificant amounts. For example, cadmium and mercury were present in such low concentrations in all of the extracts that they were judged not to be worth looking at in the following leaching and runoff simulations. Antimony and lead, meanwhile, were never found in any of the extracts, even though the levels of lead in all of the whole ash samples were quite high (70-100 mg/kg).

An interesting result of the variability data is the comparison of the recent ash samples with those collected in 1976, before the flue gas conditioning systems (SO_3 injection) were installed. The largest differences appear to be in the Benjamin ash. The older samples produce much lower concentrations of extractable arsenic and selenium and much higher concentrations of manganese, iron, nickel, and zinc and they have a much lower calcium:iron ratio. The results from the whole ash analyses

TABLE 1

RESULTS OF ASH VARIABILITY TESTS
LEACHABLE CONSTITUENTS (ug/g)

Hopper	Coal Type	Date	As	Se	Sb	Mo	B	F	Al	Mn	Fe	Ca	Total Cr	Zn	Ni	Cd	Pb	Hg
A-1	Unit #2 Greenwich	4/20/79	4.0	4.0	--	--	--	--	333.	nd	nd	4,336.	3.7	1.7	nd	nd	nd	nd
A-4	"	"	2.4	1.8	--	--	--	--	151.	nd	1.0	4,360.	2.4	4.5	nd	nd	nd	nd
A-8	"	"	2.9	1.12	--	--	--	--	102.	nd	nd	4,830.	nd	0.32	nd	nd	nd	0.006
A-9	"	"	2.7	--	--	--	--	--	250.	nd	1.6	2,638.	--	--	--	nd	--	--
A-12	"	"	3.5	--	--	--	--	--	192.	nd	nd	2,304.	--	--	--	nd	--	--
A-16	"	"	2.7	--	--	--	--	--	78.6	nd	1.0	2,672.	--	--	--	nd	--	--
A-1	Unit #2 Benjamin	4/19/79	7.4	0.32	nd	4.3	14.9	14.7	176.	4.5	8.6	2,656.	2.2	10.4	7.7	0.5	nd	--
A-4	"	"	4.3	4.6	--	--	--	--	261.	nd	1.1	2,144.	nd	0.2	--	--	nd	--
A-8	"	"	1.1	2.2	--	--	--	--	282.	nd	1.0	3,008.	nd	0.3	--	--	nd	--
A-9	"	"	4.2	--	--	--	--	--	73.1	0.5	nd	2,192.	--	--	--	--	--	--
A-12	"	"	3.7	--	--	--	--	--	12.2	0.8	2.6	2,000.	--	--	--	--	--	--
A-16	"	"	7.8	--	--	--	--	--	230.	nd	nd	1,632.	--	--	--	--	--	--
A-1	Unit #2 Greenwich	6/08/79	3.4	3.7	--	--	--	--	370.	nd	1.8	2,720.	1.9	--	nd	nd	nd	nd
A-4	"	"	3.0	4.2	--	--	--	--	293.	nd	nd	3,008.	nd	0.3	nd	nd	nd	nd
A-8	"	"	3.8	3.5	--	--	--	--	317.	nd	nd	2,800.	nd	0.2	nd	nd	nd	nd
A-9	"	"	3.7	--	--	--	--	--	782.	nd	2.1	2,240.	--	--	--	nd	--	--
A-12	"	"	5.1	--	--	--	--	--	198.	nd	nd	2,096.	--	--	--	nd	--	--
A-16	"	"	3.5	--	--	--	--	--	140.	nd	nd	1,920.	--	--	--	nd	--	--
2-B Inlet	Greenwich	5/14/76	2.5	1.12	nd	11.2	3.2	38.7	349.	nd	nd	1,512.	nd	0.64	nd	--	--	--
2-B Inlet	Benjamin	5/06/76	0.8	nd	nd	nd	3.2	81.6	414.	22.2	86.4	717.	3.8	99.2	31.8	--	--	--
2-B Inlet	Benjamin	5/05/76	0.85	nd	nd	nd	7.2	35.2	285.	25.1	88.8	1,096.	nd	191.	35.4	--	--	--
2-B Inlet	Greenwich	5/13/76	2.0	1.6	nd	9.6	9.6	26.4	126.	nd	nd	1,808.	nd	0.48	nd	--	--	--
2-B Inlet	Banjamin	12/07/76	0.03	nd	nd	nd	nd	3.0	261.	52.0	138.	653.	nd	501.	302.	--	--	--
2-B Inlet	Benjamin	12/15/76	0.11	nd	nd	nd	8.8	51.2	576.	30.6	59.2	2,080.	nd	87.2	62.4	--	--	--
B-1	Unit #2 Greenwich	7/06/79	2.2	2.24	nd	31.2	7.2	5.3	237.	nd	nd	1,664.	1.6	0.48	nd	--	--	--

NOTES:

"nd" indicates none detected.

TABLE 2

SELECTED pH, CONDUCTIVITY, AND TDS RESULTS FROM ASH VARIABILITY TESTS

Unit 2	GREENWICH				BENJAMIN			
Hopper #	Date	pH	Conductivity (uMHO)	TDS (mg/L)	Date	pH	Conductivity (uMHO)	TDS (mg/L)
A-1	4/20/79	10.2	1496	1482	4/19/80	4.1	1376	1320
A-4	"	11.3	2095	854	"	9.9	886	748
A-8	"	11.4	2645	1199	"	8.8	1367	1292
A-9	"	11.0	1277	1021	"	8.6	917	775
A-12	"	11.2	1127	809	"	7.4	877	727
A-16	"	11.6	2095	795	"	10.4	707	567
B-1	"	10.3	1496	1360	"	4.0	1338	1272
B-8	"	11.2	1195	1014	"	5.2	1308	1195
B-9	"	11.0	1417	858	"	4.7	988	844
B-12	"	11.1	1187	783	"	4.3	958	1267
B-16	"	10.9	1602	724	"	8.1	808	648
A-1	6/08/79	10.3	1101	982	6/21/79	3.9	1100	936
A-4	"	10.1	1251	1207	--	--	--	--
A-8	"	10.4	1216	1056	6/21/79	3.7	1400	1446
A-9	"	10.2	1031	933	--	--	--	--
A-12	"	10.6	887	682	--	--	--	--
A-16	"	10.7	953	568	--	--	--	--
B-1	"	10.3	1197	1163	6/21/79	3.7	1150	1126
B-4	"	11.2	1100	935	--	--	--	--
B-8	"	10.2	1050	920	6/21/79	3.9	1100	948
B-9	"	10.5	964	823	--	--	--	--
B-12	"	10.6	914	795	--	--	--	--
B-16	"	10.4	844	651	--	--	--	--

TABLE 3

RESULTS OF WHOLE ASH ATOMIC ABSORPTION AND EMISSION SPECTROGRAPHIC ANALYSIS

	Benjamin Inlet Composite 6-21-79	Greenwich Composite 4-20-79	Greenwich Composite 6-8-79	Benjamin Composite 4-19-79	Benjamin Composite 5-5-76
Al_2O_3	25.6%	25.9	26.0	26.0	26.2
Fe_2O_3	13.1%	9.59	9.60	12.9	17.1
CaO	2.08%	3.98	3.15	2.35	1.72
MnO	0.033	0.039	0.036	0.032	0.036
As	440ppm	230	190	210	280
Cd	1.4	1.5	1.6	1.2	1.1
Pb	75	70	80	80	80
Se	28	14	16	23	45

	Benjamin Inlet 5-6-76	Greenwich Inlet 5-13-76	Greenwich Inlet 5-14-76	Benjamin Inlet 12-2-76	Benjamin Inlet 12-15-76
Al_2O_3	26.6%	25.1	24.9	26.2	26.4
Fe_2O_3	16.0	8.22	8.56	15.2	15.4
CaO	1.62	2.67	2.63	1.38	1.60
MnO	0.039	0.046	0.047	0.050	0.045
As	290ppm	130	100	150	300
Cd	0.9	1.2	1.1	1.2	1.0
Pb	100	70	75	80	90
Se	50	21	21	70	44

confirm these differences. While this change in ash chemistry cannot be attributed to an exact cause, it is worth noting because it shows the magnitude of the changes which are possible from factors other than simple size sorting and chemical conditioning.

Leaching Simulations

Leaching is the process whereby certain constituents of the ash become dissolved in water as it percolates downward through the ash pile. This process can be simulated in the laboratory--at a great expense of time--by packing columns with the ash and then allowing water to pass through them. A quicker way, and one which has been shown to produce comparable results (7), is to mix the ash with water at a high solid: liquid ratio. To find out what is happening at a given level in the ash pile over time, "batches" of water representing a certain pore volume can be added to the ash and then extracted. By knowing the flow velocity through the ash under field conditions, the equivalent time of penetration for each batch of water can be calculated. A portion of each extract can then also be used to challenge another type (layer) of ash or some other material, such as a site soil. This new extract would show how the leachate changes as it moves through the pile. The overall simulation method just described is referred to as serial batchwise extraction. The specific technique followed in the present study and the associated equation for calculating equivalent time of penetration (leaching) are discussed in detail by Houle and Long (7).

Using this method three scenarios representing three different field conditions were simulated in the laboratory. The first involved a combination of Greenwich and Benjamin ashes from the outlet hoppers ("worst case" combination) overlying a typical site soil. The second involved the same combination of ashes overlying that combination again, but after partial leaching, overlying bottom ash (coarse boiler slag). The partially leached material was intended to represent ash which had been exposed for a time on the pile (aged ash). The bottom ash was being evaluated as a possible drainage blanket material. The third scenario involved a combination of Benjamin ashes from across the hopper series ("average" combination) overlying the aged Greenwich-Benjamin ash combination overlying bottom ash again. These three scenarios are shown schematically in Figure 3. The general extraction sequence is shown in Figure 4. The results of the analyses performed on the extracts are presented in Tables 4 through 6.

The site soil was also subjected to the extraction procedure to determine what constituents it might contribute to the leachate. The extraction sequence which was followed is the same as that shown in the first column of Figure 4. The analytical results are presented in Table 7.

Figure 5 illustrates how the data from the scenarios can be interpreted. Similar graphs can be prepared for all of the analysis parameters. What this one example from Scenario 1 shows is that very little arsenic is dissolved from the ash initially, apparently due to the greater solubility of other constituents, such as sulfate, which actually control the solubility of the arsenic. Selenium and chromium follow the same general

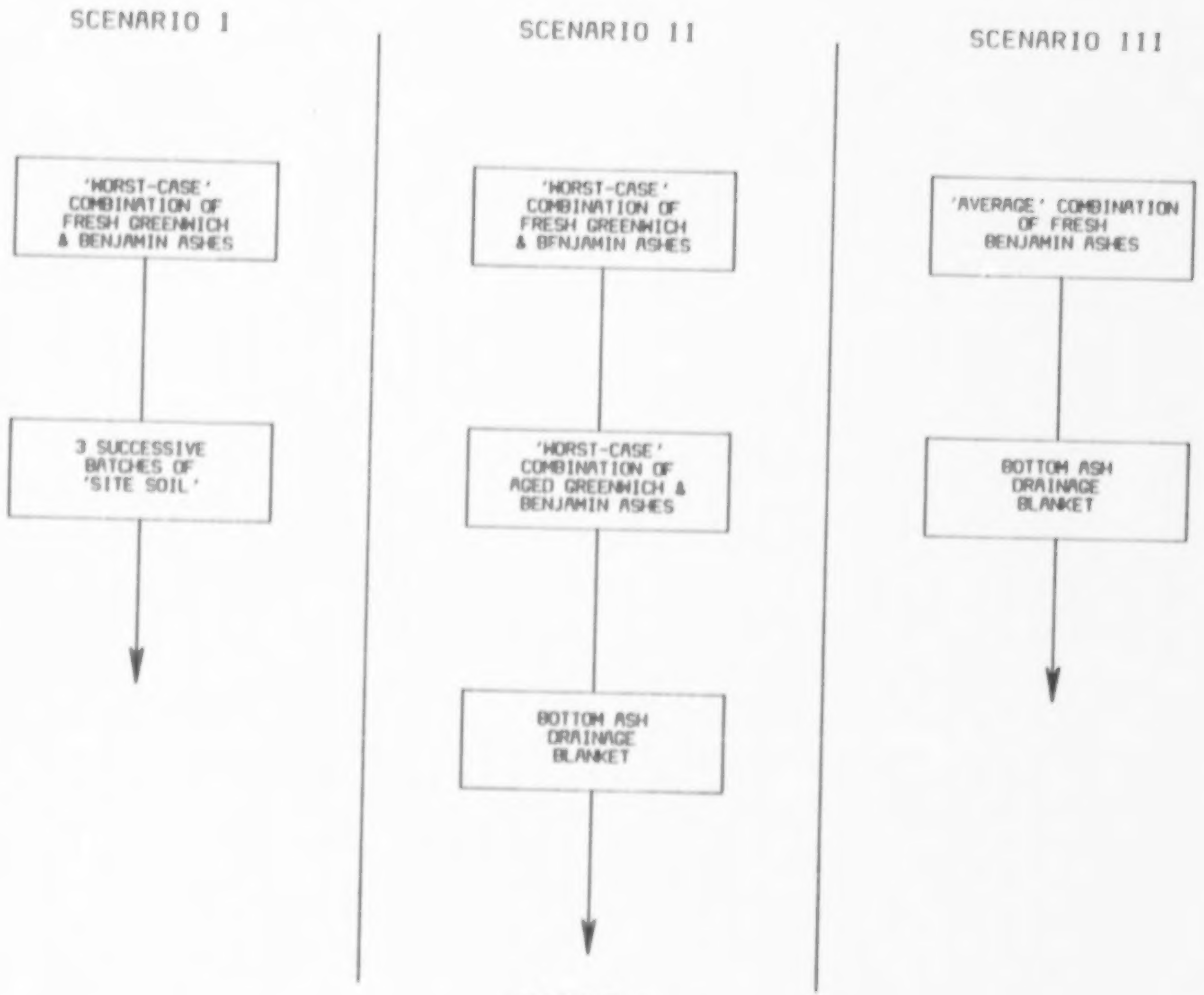
SCENARIO I
'WORST-CASE' COMBINATION OF FRESH GREENWICH & BENJAMIN ASHES
3 SUCCESSIVE BATCHES OF 'SITE SOIL'
SCENARIO II
'WORST-CASE' COMBINATION OF FRESH GREENWICH & BFNJAMIN ASHES
'WORST-CASE' COMBINATION OF AGED GREENWICH & BENJAMIN ASHES
BOTTOM ASH DRAINAGE BLANKET
SCENARIO III
'AVERAGE' COMBINATION OF FRESH BENJAMIN ASHES
BOTTOM ASH DRAINAGE BLANKET

FIGURE 3
SCENARIO SCHEMATIC

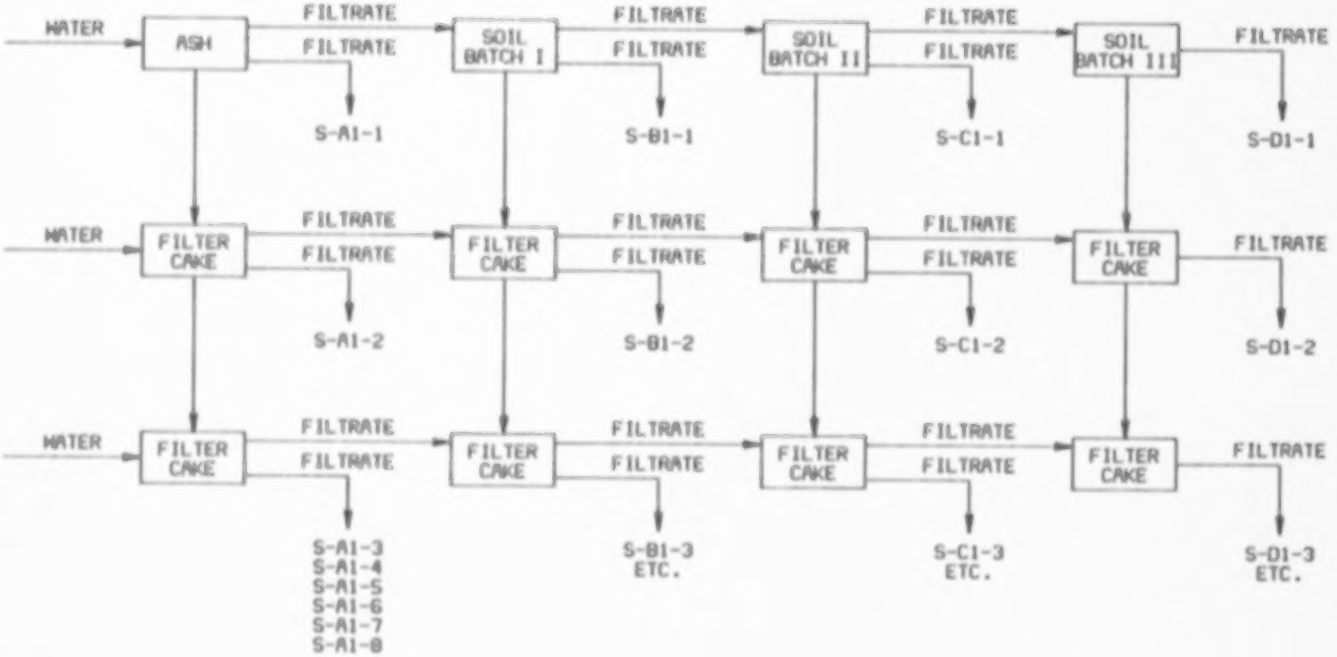
WATER
ASH
FILTRATE
FILTRATE
S-A1-1
SOIL BATCH I
FILTRATE
FILTRATE
S-B1-1
SOIL BATCH II
FILTRATE
FILTRATE
S-C1-1
SOIL BATCH III
FILTRATE
S-D1-1
WATER
FILTER CAKE
FILTRATE
FILTRATE
S-A1-2
FILTER CAKE
FILTRATE
FILTRATE
S-B1-2
FILTER CAKE
FILTRATE
FILTRATE
S-C1-2
FILTER CAKE
FILTRATE
S-D1-2
WATER
FILTER CAKE
FILTRATE
FILTRATE
S-A1-3
S-A1-4
S-A1-5
S-A1-6
S-A1-7
S-A1-8
FILTER CAKE
FILTRATE
FILTRATE
S-B1-3
ETC.
FILTER CAKE
FILTRATE
FILTRATE
S-C1-3
ETC.
FILTER CAKE
FILTRATE
S-D1-3
ETC.

FIGURE 4
GENERAL EXTRACTION SEQUENCE

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TABLE 4

SCENARIO I
EXTRACTABLE CONSTITUENTS (ug/g)

Sample Number	As	Se	Sb	Mo	B	F	Al	Mn	Fe	Ca	Total Cr	Zn	Ni	SO_4	pH	TDS	Equivalent Days of Penetration
New Fly Ash																	
S1-A1	0.068	0.68	nd	46.6	5.0	1.62	48.6	nd	nd	500	0.5	0.14	nd	3550	10.1	5620	1.8
S1-A2	0.67	0.5	nd	12.0	1.35	0.6	30.0	nd	0.42	372	nd	0.24	nd	4530	10.2	7350	4.6
S1-A3	1.29	0.70	nd	3.42	nd	1.62	49.0	nd	0.72	431	nd	0.18	nd	5160	10.0	8916	10.1
S1-A4	3.5	2.58	nd	1.8	4.8	10.9	250.0	nd	1.32	598	nd	0.24	nd	1596	10.5	4788	21.2
S1-A5	22.5	1.92	--	nd	nd	13.0	--	nd	--	955	nd	0.48	--	864	9.8	3038	43.2
S1-A6	24.0	nd	--	nd	nd	5.76	--	nd	--	979	nd	nd	--	96	9.2	2702	87.4
S1-A7	40.1	0.29	--	nd	nd	4.8	--	nd	--	1085	nd	nd	nd	96	8.9	1302	175.7
S1-A8	22.7	nd	--	nd	(8.4)	5.76	--	nd	--	(8448)	nd	nd	--	192	8.1	3821	352.4
Site Soil Batch I																	
S1-B1	nd	nd	nd	6.84	4.2	1.5	nd	0.68	nd	504	1.48	0.14	nd	3150	7.5	--	1.22 Yr
S1-B2	nd	0.054	nd	9.3	1.05	1.23	nd	0.57	nd	348	0.84	nd	--	5100	7.5	--	3.04
S1-B3	0.072	0.06	--	9.0	2.7	4.08	--	0.54	--	597	nd	nd	--	5400	7.8	--	6.7
S1-B4	0.17	0.12	nd	7.2	3.6	17.5	nd	nd	nd	521	nd	nd	nd	1956	8.2	--	13.9
S1-B5	2.04	nd	--	20.2	nd	--	--	--	--	1764	nd	--	--	--	8.4	--	28.6
S1-B6	29.8	1.44	--	(67.2)	--	--	--	--	--	1334	nd	--	--	--	8.1	--	57.8
S1-B7	35.5	nd	--	nd	--	--	--	--	--	(6144)	nd	--	--	--	7.8	--	116.2
S1-F8	24.0	(7.7)	--	(67.2)	nd	--	--	--	--	(15360)	nd	--	--	--	7.5	--	233
Site Soil Batch II																	
S1-C1	0.04	0.022	--	--	--	--	--	0.54	0.7	--	3.28	0.28	nd	--	7.2	--	1.22 Yr
S1-C2	nd	0.03	nd	4.8	1.86	1.86	nd	0.78	nd	1296	1.74	0.21	nd	4305	7.2	--	3.04
S1-C3	0.03	nd	--	17.1	nd	3.78	nd	nd	nd	756	nd	nd	nd	6300	7.2	--	6.7
S1-C4	0.04	nd	nd	33.6	5.4	12.1	--	nd	--	1019	nd	1.8	nd	--	7.3	--	13.9
S1-C5	0.38	--	--	--	nd	31.4	--	nd	--	--	--	--	--	--	7.4	--	28.6
S1-C6	9.8	--	--	--	--	--	--	--	--	--	--	--	--	--	7.5	--	57.8
S1-C7	25.3	--	--	--	--	--	--	--	--	--	--	--	--	--	7.5	--	116.2
S1-C8	24.2	--	--	--	--	--	--	--	--	--	--	--	--	--	7.4	--	233
Site Soil Batch III																	
S1-D1	nd	nd	nd	nd	1.16	1.4	nd	0.54	nd	328	2.82	0.18	nd	3150	7.3	--	1.22 Yr
S1-D2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.2	4.6	3.04
S1-D3	nd	nd	--	15.0	2.4	4.08	--	nd	--	1512	2.46	0.3	--	5550	7.2	--	6.7
S1-D4	nd	nd	nd	52.8	nd	9.36	nd	nd	nd	2052	nd	nd	nd	--	7.1	--	13.9
S1-D5	0.17	--	--	12.0	nd	31.9	--	nd	--	2098	nd	nd	--	--	7.3	--	28.6
S1-D6	--	--	--	--	--	--	--	--	--	--	nd	--	--	--	7.3	--	57.8
S1-D7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.3	--	116.2
S1-D8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.4	--	233

NOTES:

Scenario I involves a combination of fresh Greenwich and Benjamin fly ashes from hoppers A-1 and B-1 in direct contact with site soil.
"nd" indicates none detected.
"()" indicate a possible "outlier" value.

TABLE 5

SCENARIO 2
EXTRACTABLE CONSTITUENTS (ug/g)

Sample Number	As	Se	Sb	Mo	B	F	Al	Mn	Ca	SO_4	pH	TDS	Equivalent Days of Penetration
New Fly Ash													
S2-A1	0.072	0.58	nd	39.	4.32	--	43.6	nd	308	1720	9.9	5260	1.8
S2-A2	0.24	0.54	nd	9.54	nd	--	72.	nd	732	5370	10.2	7350	4.6
S2-A3	0.70	0.60	nd	3.78	nd	--	95.6	nd	1278	5040	10.0	8220	10.1
S2-A4	3.34	nd	nd	1.8	nd	--	99.7	nd	594	606	9.8	1740	21.2
S2-A5	8.62	1.68	nd	2.64	nd	--	--	--	725	--	9.6	2388	43.2
S2-A6	23.7	1.92	nd	nd	nd	--	--	--	266	--	9.3	2981	87.4
S2-A7	39.8	0.96	nd	nd	nd	--	--	--	(4512)	--	7.9	2707	175.7
S2-A8	30.3	nd	nd	15.36	nd	--	--	--	1674	--	7.1	(10330)	352.4
Aged Fly Ash													
S2-B1	0.68	0.14	nd	39.	3.42	--	9.8	nd	600	3280	9.2	--	1.8
S2-B2	0.73	0.03	nd	8.34	nd	--	24.0	nd	426	4440	9.3	--	4.6
S2-B3	1.07	0.36	nd	3.3	--	--	72.	nd	1734	5760	9.2	8880	10.1
S2-B4	3.66	1.56	nd	2.76	nd	--	168.	nd	525	1392	10.0	3492	21.2
S2-B5	11.0	2.88	nd	(28.8)	nd	--	--	--	1397	--	9.8	3936	43.2
S2-B6	36.6	2.88	nd	3.84	nd	--	--	--	2150	--	8.9	3989	87.4
S2-B7	73.2	3.84	nd	7.68	nd	--	--	--	3936	--	8.6	5741	175.7
S2-B8	77.6	nd	nd	15.36	nd	--	--	--	(10330)	--	8.4	5779	352.4
Bottom Ash													
S2-C1	nd	nd	nd	0.76	4.24	nd	nd	14.0	36	5024	3.0	--	0.005
S2-C2	nd	nd	nd	0.36	4.53	0.93	9.8	1.11	1116	5160	4.6	--	0.013
S2-C3	0.23	nd	nd	6.27	2.64	1.20	12.8	0.48	1908	7680	7.8	8340	0.03
S2-C4	0.17	nd	nd	11.4	nd	11.88	60.2	nd	802	2076	8.7	3420	0.06
S2-C5	7.27	0.65	nd	3.6	nd	13.68	--	--	1488	--	9.0	3888	0.12
S2-C6	33.4	1.44	nd	3.84	(21.12)	17.28	--	--	3034	--	8.6	3744	0.25
S2-C7	73.2	3.84	nd	nd	nd	15.36	--	--	(6192)	--	8.5	5453	0.5
S2-C8	86.0	nd	nd	nd	nd	11.52	--	--	(12000)	--	7.3	6278	1.0

NOTES:

Scenario 2 involves a combination of fresh Greenwich and Benjamin fly ashes from hoppers A-1 and B-1 challenging a combination of "aged" Greenwich and Benjamin fly ashes and bottom ash.
"nd" indicates none detected.
"()" indicate a possible "outlier" value.

TABLE 6

SCENARIO 3
EXTRACTABLE CONSTITUENTS (ug/g)

Sample Number	As	Se	Mo	B	F	Mn	Total Cr	Ni	SO_4	pH	TDS	Equivalent Days of Penetration
New Fly Ash												
S3-A1	0.26	0.58	28.0	5.84	7.50	nd	0.18	nd	3820	9.7	5798	1.8
S3-A2	0.48	0.48	4.8	nd	3.45	--	nd	nd	4620	10.1	6519	4.6
S3-A3	0.78	0.69	1.14	--	5.46	--	nd	nd	1170	10.1	2550	10.1
S3-A4	5.52	1.72	nd	--	6.72	--	nd	nd	415	9.9	1632	21.2
S3-A5	18.0	0.34	--	--	4.80	--	nd	nd	214	9.2	1226	43.2
S3-A6	26.9	0.16	--	--	3.36	nd	nd	nd	86.4	8.8	1094	87.4
S3-A7	127.	0.10	--	--	4.80	(3.84)	nd	(13.4)	355	7.8	3168	175.7
S3-A8	21.1	nd	--	--	5.76	nd	nd	nd	384	7.2	6624	352.4
Aged Fly Ash												
S3-B1	0.86	0.15	20.6	4.22	0.68	nd	0.72	nd	--	9.6	--	1.8
S3-B2	1.26	0.08	7.7	3.6	0.90	--	0.39	--	--	9.1	--	4.6
S3-B3	1.56	0.91	2.1	nd	4.50	--	nd	--	2340	9.4	3798	10.1
S3-B4	3.84	0.95	nd	nd	10.56	--	nd	--	900	10.2	2808	21.2
S3-B5	16.8	2.42	--	--	--	--	nd	--	797	9.8	3120	43.2
S3-B6	49	0.10	--	--	--	--	nd	--	749	9.3	3811	87.4
S3-B7	57.6	0.23	--	--	--	--	nd	--	643	9.0	4848	175.7
S3-B8	3.84	0.33	--	--	--	--	nd	--	288	5.9	6624	352.4
Bottom Ash												
S3-C1	0.06	nd	1.54	4.32	4.0	15.62	1.14	162.5	--	3.1	--	0.005
S3-C2	0.01	nd	nd	3.18	1.02	1.08	nd	22.6	--	3.7	--	0.013
S3-C3	0.06	0.02	3.5	nd	2.88	nd	nd	0.66	3870	8.2	5172	0.03
S3-C4	0.24	0.01	8.5	nd	16.20	nd	nd	nd	1158	8.7	2532	0.06
S3-C5	3.6	0.89	--	--	--	--	nd	--	1104	9.0	2784	0.12
S3-C6	39.8	0.72	--	--	--	--	nd	--	739	8.9	3758	0.25
S3-C7	70.0	1.44	--	--	--	--	nd	--	739	8.5	3514	0.50
S3-C8	57.6	1.11	--	--	--	--	nd	--	384	7.6	6451	1.0

NOTES:

Scenario 3 involves a combination of fresh Benjamin fly ashes from hoppers A-4, A-8, A-9, A-12, A-16, B-8, B-9, B-12, and B-16 challenging a combination of "aged" Greenwich and Benjamin fly ashes and bottom ash (same as in Scenario 2).
"nd" indicates non detected.
"()" indicates a possible "outlier" value.

TABLE 7

SITE SOIL EXTRACTIONS
EXTRACTABLE CONSTITUENTS (ug/g)

Sample Number	As	Se	Sb	Mo	B	F	Al	Mn	Fe	Ca	Total Cr	Zn	Ni	Total C	SO_4	pH	TDS	Equivalent Days of Penetration
SX-1	0.012	0.008	nd	0.44	1.26	1.6	nd	0.2	nd	156.	1.48	0.12	nd	30	670	7.1	1402	1.22
SX-2	0.018	nd	nd	1.32	nd	3.75	nd	nd	nd	52.8	1.23	nd	nd	39	153	7.4	486	3.04
SX-3	0.072	nd	nd	3.48	nd	7.32	10.2	nd	1.62	232.	0.78	0.36	nd	42	60	7.6	2292	6.7
SX-4	0.108	nd	nd	8.4	5.4	11.3	nd	nd	nd	30.6	nd	nd	nd	72	12	7.7	2200	13.9

NOTES:

SX-1 indicates the first site soil extraction, etc.
"nd" indicates none detected.

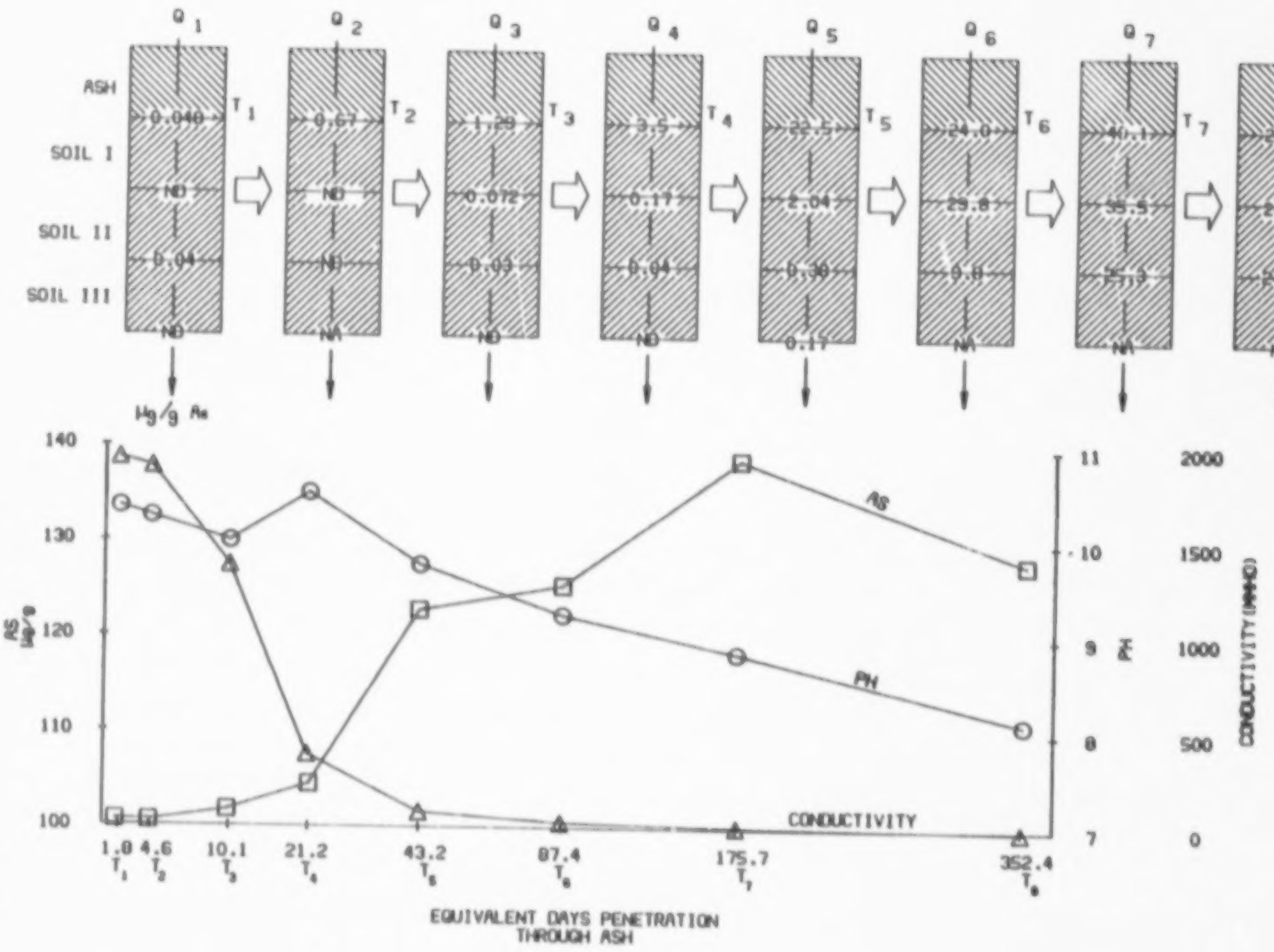


FIGURE 5
INTERPRETATION OF SCENARIO 1
ARSENIC DATA

release pattern. After about three simulated months of leaching the concentrations of the metal in solution increase dramatically as the more soluble constituents are removed from the system. This increase continues for a while and then the concentrations begin to slowly decline. In the soil the arsenic is retained at first, but then it passes through without appreciable attenuation.

Another interesting aspect of the results is presented by the pH data. In the variability tests the pH values ranged between 4 and 11 for the Benjamin and Greenwich ashes, respectively, while in the batchwise extractions they never got below 7 after one simulated year of leaching. This shows the value of not relying exclusively on a simple "shaker" type of test to determine the leaching characteristics of a solid waste.

Since the serial batchwise extractions were carried out under essentially equilibrium conditions (the reaction vessel was stirred until the time rate of change of pH and conductivity reached zero) and at a constant solid:liquid ratio, a question remained as to what the very first leachate generated at the moving front of the wetting mass would look like. To answer this question a separate series of extractions (wetting front tests) was performed on the worst-case Greenwich and Benjamin ash combination and on the average Benjamin combination. Basically, what was done was to add fresh ash to each successive extract to determine maximum solubilities of the various constituents of interest; however, mixing times did not exceed 30 minutes, compared to two hours for the batchwise extractions. The extraction sequence is shown by the top row of Figure 4 and the analytical results are given in Table 8. Generally, this data served to verify the concentration ranges already established in the variability tests and scenarios, except that the pH values tended to be very low (in the range of about 3 to 4). This was probably due to the short mixing times involved, which apparently favor the release of early acid-producing constituents from the ash.

Using these ranges, which are summarized in Table 9, it was then possible to determine the concentrations of certain pollutants likely to appear in the leachate at the bottom of the landfill. This was done by assuming that 2-5% of all the precipitation which falls on the ash will infiltrate it (these are laboratory values, although they have also been verified by actual field experience). By knowing the volume of water which infiltrates the ash pile (about 20,000 gal/yr per 5-acre segment based on an annual precipitation for the site of about 43 inches and a 2% infiltration rate) and the pounds of extractable constituents per ton of ash, the concentrations of those constituents in the leachate can then be calculated for different stages of development of the landfill. The results of these calculations are given in Table 10 for arsenic, selenium, and sulfate, which when compared to the EPA's primary (health based)

TABLE 8

WETTING FRONT TEST #1
EXTRACTABLE CONSTITUENTS (ug/g)

Sample Number	As	Se	Mo	B	F	Al	Mn	Ca	TDS
W1-1	0.74	nd	0.16	13.2	1.22	39.4	5.08	408	6646
W1-2	1.22	nd	0.34	25.2	0.2	252.	11.9	564	9348
W1-3	2.44	nd	0.7	39.2	0.18	398.	18.4	298	13372

NOTES:

This test involved a combination of fresh Greenwich and Benjamin fly ashes from hoppers A-1 and B-1.
"nd" indicates none detected.

WETTING FRONT TEST #2
EXTRACTABLE CONSTITUENTS (ug/g)

Sample Number	As	Mo	B	F	Mn	TDS
W2-1	0.18	9.64	7.82	1.26	0.74	5766
W2-2	0.8	0.34	14.96	0.2	4.34	6398
W2-3	0.76	0.86	25.0	9.1	5.86	7408
W2-4	0.5	2.9	27.2	0.72	5.96	7946

NOTE:

This test involved a combination of fresh Benjamin fly ash from hoppers A-4, A-8, A-9, A-12, A-16, B-8, B-9, B-12 and B-16.

TABLE 9

AVERAGE AND MAXIMUM CONCENTRATIONS OF CONSTITUENTS APPEARING AT THE BOTTOM OF INDIVIDUAL LAYERS IN SCENARIOS 1, 2, AND 3 (ug/g)

Parameter	Concentration	Scenario 1		Scenario 2		Scenario 3	
		Ash	Soil	Fly Ash	Bottom Ash	Fly Ash	Bottom Ash
As	Avg.	14.4	0.04	25.6	25.0	16.8	21.4
	Max.	40.1	0.17	77.6	86.0	57.6	70.0
Se	Avg.	1.11	nd	1.67	0.74	0.05	0.52
	Max.	2.58	--	3.84	3.84	2.42	1.44
Sb	Avg.	nd	nd	nd	nd	na	na
	Max.	--	--	--	--	--	--
Mo	Avg.	16.0	19.9	11.5	3.28	10.1	3.4
	Max.	46.6	52.8	15.4	11.4	20.6	8.5
B	Avg.	3.72	0.89	3.42	1.63	3.91	1.9
	Max.	4.8	2.4	3.42	4.53	4.22	4.32
F	Avg.	5.51	11.7	nd	10.3	4.16	6.02
	Max.	13.0	31.9	--	17.28	10.56	16.2
Al	Avg.	94.4	nd	68.5	20.7	na	na
	Max.	250.	--	168.	60.24	--	--
Mn	Avg.	nd	0.13	nd	3.9	nd	4.2
	Max.	--	0.54	--	14.0	--	15.62
Fe	Avg.	0.82	nd	na	na	na	na
	Max.	1.32	--	--	--	--	--
Ca	Avg.	703.	1498.	1538.	1397.	na	na
	Max.	1085.	2098.	3936.	3034.	--	--
Cr (Total)	Avg.	0.5	1.06	na	na	0.56	0.14
	Max.	0.5	2.82	--	--	0.72	1.14
Zn	Avg.	0.26	0.12	na	na	na	na
	Max.	0.48	0.3	--	--	--	--
Ni	Avg.	nd	nd	na	na	nd	23.2
	Max.	--	--	--	--	--	162.5
SO_4	Avg.	2011.	4350.	3718.	4984.	853.	1332.
	Max.	5160.	5550.	5760.	7680.	2340.	3870.
TDS	Avg.	4942.	na	5303.	5187.	4168.	4035.
	Max.	8916.	--	8880.	8340.	6624.	6451.

NOTES:

"Outliers" from Tables 4 through 6 were not used in calculations.
"nd" indicates none detected.
"na" indicates no analyses.

TABLE 10

CALCULATED CONCENTRATIONS OF SELECTED POLLUTANTS IN LEACHATE

Pollutant	Maximum Concentration (mg/L)	Average Concentration (mg/L)	EPA Drinking Water Standard (mg/L)
Arsenic	0.83	0.25	0.05
Selenium	0.04	0.01	0.01
Sulfate	1600	135	250

NOTE:

Values are based on an average annual precipitation of 43 inches and 2% infiltration rate into the ash pile.

drinking water standards appear to represent the greatest potential problem. Interestingly, the Scenario 1 data also indicates that these same constituents are not likely to be significantly attenuated by the site soil, which suggests the need to intercept the leachate for possible treatment or dilution with the other waste streams emanating from the landfill, such as runoff.

Runoff Simulations and Modeling

Stormwater runoff from the proposed landfill was simulated in the laboratory by using a modification of a technique developed by IU Conversion Systems, Inc. (8). The purpose of the simulations was to provide input to the computer model on runoff quality and flow. The IUC technique basically involves packing a metal box with the ash to approximate field conditions, preparing the surface (rough, smooth, baked with a heat lamp to simulate prolonged exposure to intense sunlight, and so on), and then spraying reagent grade water over the surface. The resulting runoff is caught and recirculated for one hour. By using a constant flow rate over a known surface area, each simulation represents a one hour rainfall of a certain intensity running off a unit area of ash. The result is a family curves relating inches of rain to linear feet of runoff for different application rates (storm intensities). These curves are presented in Figure 6.

An average Greenwich and average Benjamin ash (equal-volume grab samples from the inlet and outlet hoppers) were used for the simulations. pH and conductivity were monitored continously in the recirculated runoff. The average pH of all the runoff water for both ash types was 6.0, although the Greenwich runoff had an average pH of about 6.1 and the Benjamin Runoff an average pH of 5.8. This contrasts with the drastically different pH values found for the two ash types in the variability tests. During each simulation, the initial runoff pH was about 5.5 and then slowly increased to neutral or slightly above. Conductivity followed the same pattern, starting at about 40 umhos and ending at about 800. The results of the analyses performed on the final runoff for the other parameters of interest are given in Table 11. Generally, they are consistent with the results from the variability tests and so do not deserve further discussion here.

The computer model selected for the second phase of the runoff analysis is a modification of EPA's Short Stormwater Management Model (SSWMM). The modification was necessary to allow consideration of the pollutants in the runoff, rather than just the runoff flow. The model addresses washoff, surface detention, depression storage, and infiltration, but does not look at how this infiltration might change the runoff characteristics. Instead, it focuses on pollutant transport by overland flow and channel routing and the exponential decay of pollutants through washoff.

While the runoff simulator was exposed to a constant rate and volume of precipitation, the model processed storms with varying intensities and total precipitation amounts. Five storm events representing a broad range of storm types were selected for analysis. These storms are characterized in Table 12. Total precipitation values for the area were obtained from U.S. Weather Bureau data (9). Published statistical hyetographs for 10% and 50% probability storms were used to show how

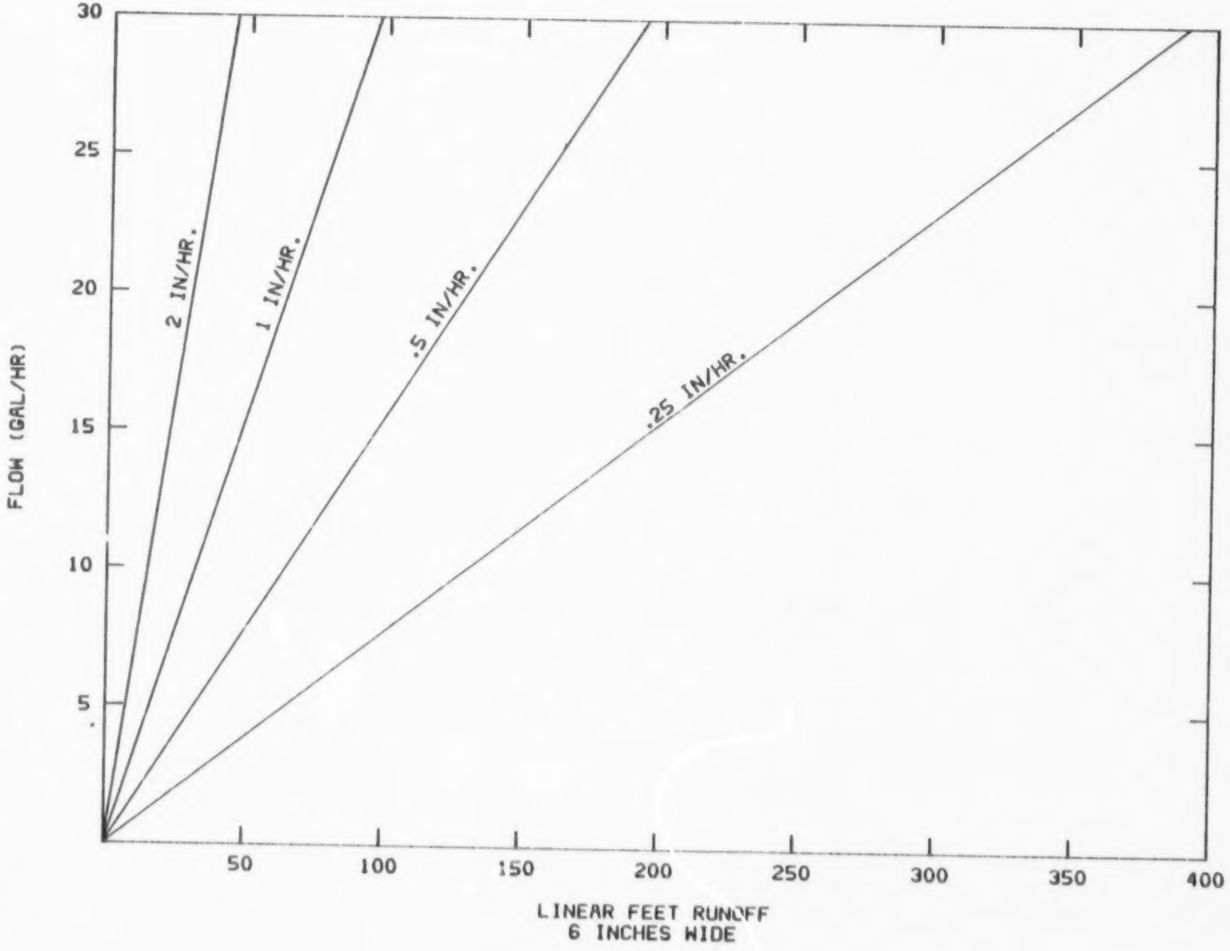


FIGURE 6
SIMULATED FLOW-RUNOFF

TABLE 11

SELECTED RUNOFF SIMULATOR TEST RESULTS

Sample Description Source Hopper No.		Rough Compact Benjamin $A_1B_1A_8B_8$	Sun Dried Benjamin $A_1B_1A_8B_8$	Compacted Benjamin $A_1B_1A_8B_8$	Compacted Greenwich $A_1B_1B_8$	Rough Compact Greenwich $A_1B_1B_8$
Bearing Cap. (tons/ft^2)		1.25	1.41	1.78	3.69	1.25
Thickness of Ash (in.)		6	6	6	4	4
% Moisture		20	20	20	20	20
Avg. Test Flow (gph)		11.9	15.2	14.9	16.7	17.8
Vol. of Water Retained(ml)		1400	1500	0	100	0
Analyses:						
Avg. pH		--	--	5.8	6.0	6.6
Avg. Cond.	umho	--	--	420	458	240
TSS	mg/l	6564.	47864.	37568.	40662.	24165.
TDS	mg/l	714.	1076.	799.	1060.	556.
Sett. Solids	mg/l	--	--	38.38	78.78	32.91
As	mg/l	.085 *	.100 *	6.19	0.66	3.34
Al	mg/l	nd *	nd *	399.	36.2	70.0
Ca	mg/l	66.5 *	58.5 *	204.	475.	207.
Fe	mg/l	nd *	nd *	nd *	nd *	--
		--	--	114.	0.41	12.1
Cr	mg/l	nd *	nd *	nd *	nd *	--
		--	--	1.09	0.26	0.80
Ni	mg/l	nc	nd	--	--	--
Se	mg/l	nd *	0.03	0.05?*	0.006	0.019
		--	--	0.14	nd *	--
Zn	mg/l	0.08 *	0.03 *	0.04 *	0.98	0.65
		--	--	2.34	--	--
B	mg/l	0.75 *	nd *	questionable data	15.4	19.6
F	mg/l	0.22 *	0.43 *	1.0	0.26	0.27
Sb	mg/l	nd *	nd *	--	--	--
Mo	mg/l	0.91	1.10 *	0.430	0.196	0.311
Mn	mg/l	0.05 *	0.08 *	--	--	--
SO_4	mg/l	493. *	718. *	452.	605.	252.

NOTES:

"*" indicates dissolved; otherwise, total.
"nd" indicates none detected.

TABLE 12

CHARACTERISTICS OF MODELED STORM EVENTS

Storm Event	Description	Total Rainfall (in.)
1-Year/30-Minute	Summer thunder shower	0.8
1-Year/2-Hour	Series of summer thunder showers	1.3
1-Year/6-Hour	Heavy rain preceding frontal passage (spring, fall)	1.8
1-Year/24-Hours	Moderate, steady rain	2.3
10-Year/24-Hours	Heavy, steady rain	4.5

rainfall intensity varies with time for short- and long-duration storm events, respectively.

The modified SSWMM model evaluated 13 pollutants; however, it could not be calibrated independently for each. As a result, only two pollutants, arsenic and selenium, were selected as the focus of the calibration. The model was calibrated to 0.1 milligrams for these two pollutants and within one order of magnitude for sulfate, although it consistently predicted total dissolved solids at much lower levels than the measured values of 700-1400 milligrams per liter.

Figures 7 and 8 show how the concentrations of selected pollutants change for the runoff from Greenwich ash during a short and long storm event. The curves for the Benjamin ash are very similar. Also shown is how the runoff flow changes. Table 13 is a summary of the pollutant concentrations in the total runoff, assuming all of it is collected. Interestingly, these concentrations are not significantly different for the two types of ash and do not vary at all with the storm event; however, the arsenic and selenium levels consistently exceed the EPA's primary drinking water standards. This again suggests the need for some sort of treatment or flow combination.

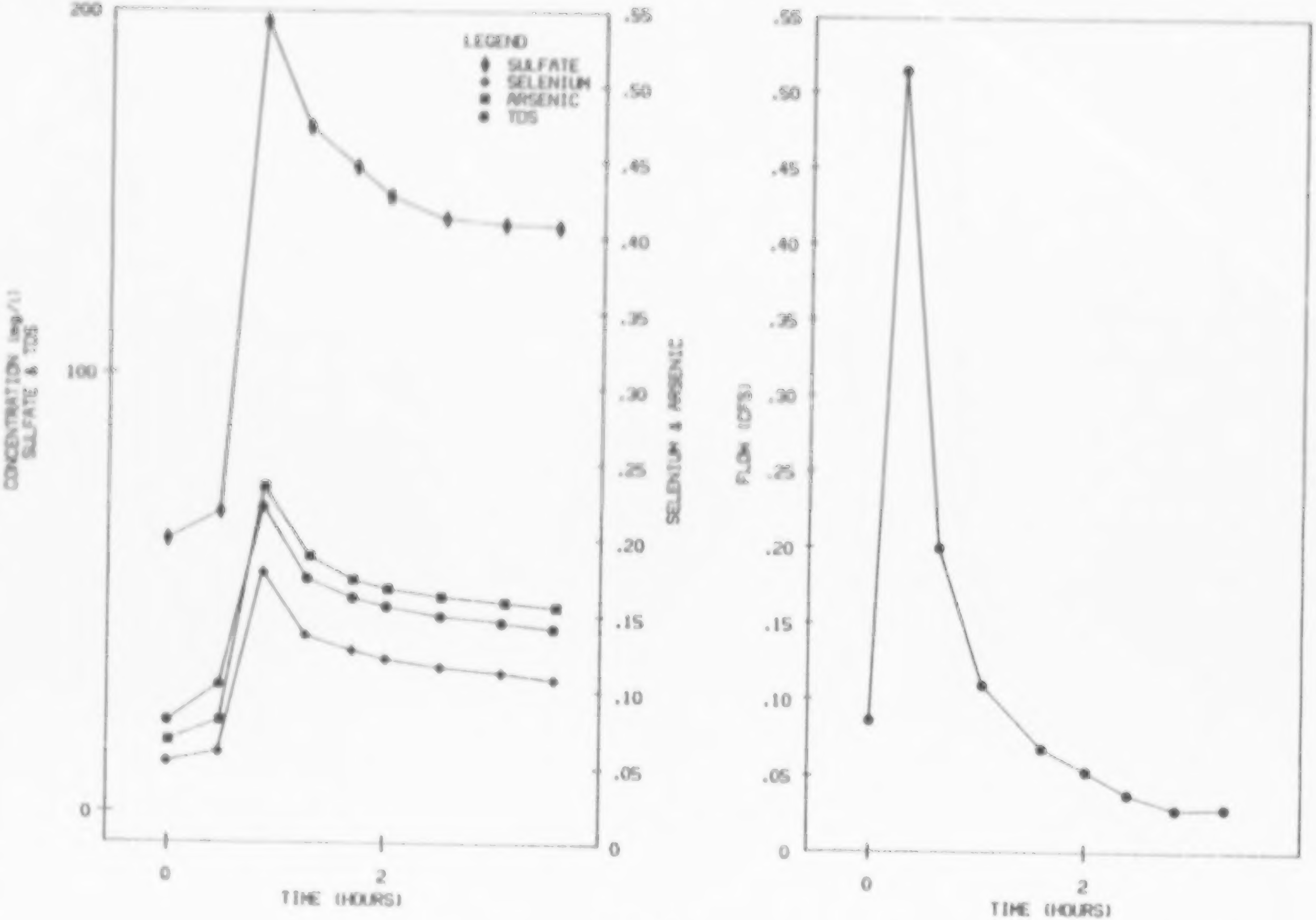


FIGURE 7
MODELED 1-YEAR/30-MINUTE STORM RUNOFF
CHARACTERISTICS FOR GREENWICH ASH

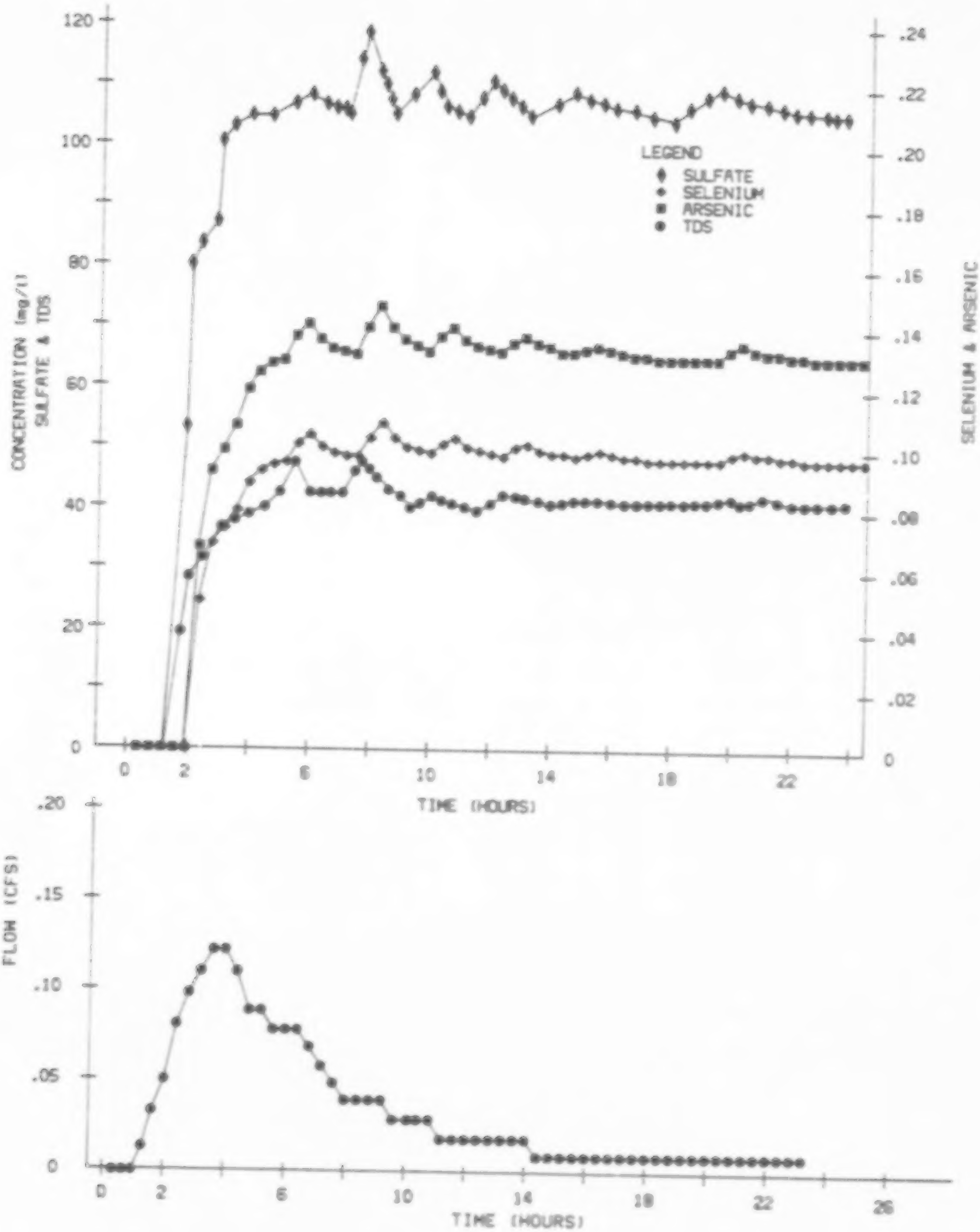


FIGURE 8
MODELED 1-YEAR/24-HOUR STORM RUNOFF
CHARACTERISTICS FOR GREENWICH ASH

TABLE 13

RESULTS OF MODIFIED SWMM MODEL FOR A 5-ACRE ASH AREA

Storm Event	Ash	Runoff Volume (gal)	Total Pollutant Load Washed Off Ash Pile (lbs)				Pollutant Concentration in Hypothetical Collection Pond (mg/l)			
			As	Se	SO_4	TDS	As	Se	SO_4	TDS
1-year/30-minute	Benjamin	11,848	0.02	0.01	9.1	4.2	0.18	0.10	90.8	42.0
	Greenwich		0.01	0.01	11.0	3.9	0.14	0.10	109.8	38.9
1-year/2-hour	Benjamin	24,235	0.04	0.02	18.4	8.5	0.18	0.11	90.6	41.9
	Greenwich		0.03	0.02	22.3	7.9	0.14	0.10	109.5	38.8
1-year/6-hour	Benjamin	36,188	0.05	0.03	27.5	12.7	0.19	0.11	91.1	42.1
	Greenwich		0.04	0.03	33.3	11.8	0.14	0.10	110.2	39.1
1-year/24-hour	Benjamin	32,418	0.03	0.02	15.9	7.3	0.18	0.10	87.1	40.2
	Greenwich		0.02	0.02	19.2	6.8	0.13	0.10	105.3	37.3
10-year/24-hour	Benjamin	47,176	0.07	0.04	34.1	15.8	0.18	0.10	86.4	40.0
	Greenwich		0.05	0.04	41.3	14.6	0.13	0.09	104.4	37.0
			EPA Drinking Water Standard				0.05	0.01	250.	500.

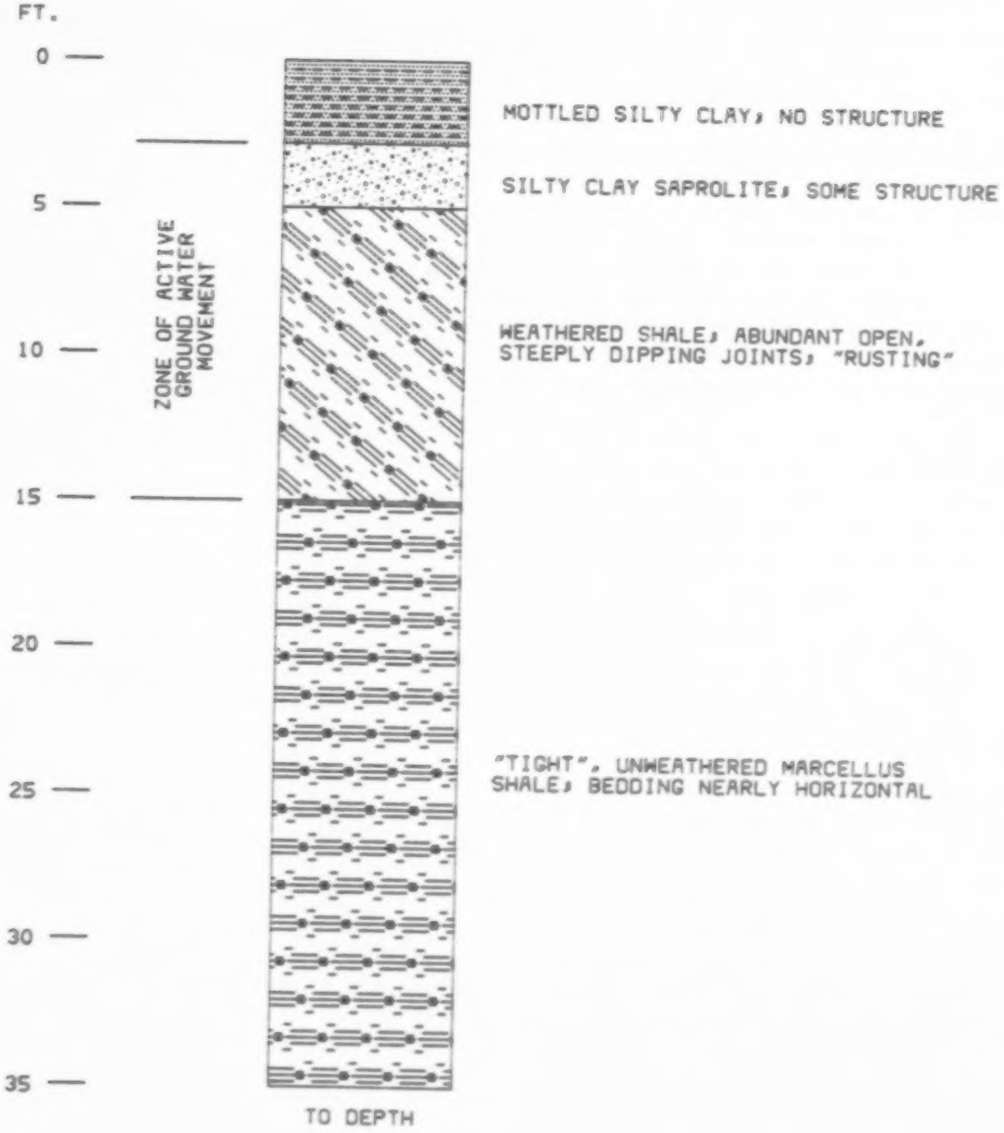
Investigation of Site Geohydrology

The 170-acre site of the planned fly ash landfill is located about one-half mile from the generating station (Figure 1). It is relatively flat-lying, with the maximum relief being only about 55 feet. Several intermittent streams cut across the site, although the majority of them appear to be diversion channels constructed for the purpose of drainage control. Prior to its being purchased by PP&L, the land was used for the farming of crops.

Geohydrological conditions at the site were investigated by means of test borings, test pits, hand auger holes, monitoring wells, and field examinations. What emerged is a picture of a fairly simple ground water aquifer system. This system is depicted in the generalized geologic section of Figure 9. Basically, the majority of ground water flow is confined to a rather narrow zone represented predominantly by a weathered and highly fractured shale. Immediately above this zone is a uniform silty clay of extremely low permeability, which acts as a cap on the ground water aquifer. Below it is a very tight (few open fractures) unweathered shale with nearly horizontal bedding, which acts as a bottom confining layer on the aquifer.

The hydraulic gradient over the site is about 1:120 and the rate of ground water flow is probably on the order of only 0.05 feet per year (based on a calculation using an assumed value for the permeability of the fractured shale). The water table occurs at a depth of 5 to 10 feet and its configuration generally conforms to the site topography. Unlike the drainage ditches, which are probably perched on top of the clayey soil, the one large intermittent stream which traverses the site appears to be connected to the ground water system, since the ground water contours indicate a depression in that area. This is worth knowing, because the stream is located along the down-gradient border of the site and could therefore possibly be used as a hydraulic barrier against the migration of any pollutants which might enter the ground water system upstream.

Local wells in the area range in depth from about 30 feet for those that were hand dug to nearly 300 feet for those that were drilled. The water is used predominantly for human consumption and livestock watering. The quality of the water is generally acceptable for these purposes, except that it contains unusually high concentrations of sulfur and iron due to the presence of iron sulfide minerals in the local bedrock. Thus, any pollutant introduced into the ground water might have an impact which should be considered in the overall design concept for the landfill.


FT.
0
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ZONE OF ACTIVE GROUND WATER MOVEMENT
MOTTLED SILTY CLAY, NO STRUCTURE
SILTY CLAY SAPROLITE, SOME STRUCTURE
WEATHERED SHALE, ABUNDANT OPEN, STEEPLY DIPPING JOINTS, "RUSTING"
"TIGHT", UNWEATHERED MARCELLUS SHALE, BEDDING NEARLY HORIZONTAL
TO DEPTH

FIGURE 9
GENERALIZED GEOLOGIC SECTION

THE LANDFILL DESIGN CONCEPT AND PLAN OF OPERATIONS

The laboratory simulations and modeling and the geohydrological investigation provided valuable input into determining how the fly ash landfill should be designed and operated.

First, the leaching simulations showed that certain pollutants, such as arsenic, selenium, and possibly sulfate, would likely appear in the leachate in concentrations above the EPA's drinking water standards for protecting human health. They also showed that these same pollutants could not be expected to be attenuated to any great extent by the site soil. From the geohydrological investigation it was found that attenuation by dilution could not be relied on either because of the slow rate of ground water movement and the confined nature and limited vertical extent of the ground water aquifer system.

Thus, it was decided to collect all of the leachate for possible treatment or combination with other waste streams, either on site or back at the generating station. What was especially appealing about this scheme was that no special liner would be required, since the natural clays at the site could serve this purpose with the need for only simple in-place reworking to remove any remnant structures (open fractures) which might still be present from weathering of the parent rock material. Physical tests performed on the station's bottom ash also showed it to be quite suitable as a drainage blanket material, except that a filter fabric of some sort would have to be used on top of the blanket to prevent its becoming clogged with the finer fly ash particles.

The results from the runoff simulations showed that, despite the storm event involved, the collected runoff from the operating portions of the landfill would again contain concentrations of arsenic and selenium in excess of the drinking water standards. While it was uncertain what discharge limitations might be placed on the outfall pipe from a collection facility, the available receiving streams in the area are so small that no in-stream dilution could be relied upon to assure compliance with water quality criteria. After all, it was the violation of these criteria that necessitated the switch from a wet to a dry ash handling system in the first place. To reduce the volume of contaminated runoff likely to be produced by the landfill, the size of the active portion could be reduced. This has the added benefit of also reducing the potential fugitive dusting problem, as well as the amount of leachate. A working cell size of 5 acres was finally selected as representing the best compromise between these concerns and operating efficiency.

The problem of what to do with the leachate and "dirty" runoff (as compared to the "clean" runoff from unworked or revegetated portions of the landfill) is still being addressed. One alternative, which has received additional study effort, involves combining the two waste streams with enough clean runoff to lower the pollutant concentrations in the final discharge to an acceptable level. This scheme has a great deal of appeal because it would eliminate the need to install a sophisticated metals treatment system based exclusively on laboratory generated data. A drawback of the scheme is that it would require a fairly large collection pond. Calculations show, for instance, that it would take about 50 acres of clean runoff to adequately lower the pollutant levels in the leachate (assuming full site development and 5% infiltration of the precipitation falling on the landfill). The problem with constructing such a large basin is that the thinness of the site soil and the low relief at the site may limit the capacity which can be achieved by excavation or diking while still allowing gravity flow into the basin.

An alternative is to pump the leachate and dirty runoff back to the generating station for combination in the waste detention pond, which also has some pH control capability. A disadvantage of this scheme is that it would require a very reliable pumping system; and should that system fail, the collected wastes would have to be discharged with essentially no reduction in pollutant concentrations. This may not be acceptable under the EPA's developing Best Management Practices requirements. Also, there is the concern that the chemistry of the leachate and runoff may not be compatible with the other wastes in the detention pond and may create a new problem at that location, even with adequate pH control.

As a means of verifying the laboratory data, another step being considered by the company is to prepare and monitor a test plot at the landfill site. Based on this data it should be possible to make a more definite decision about the need for treatment and the advisability of the various flow combination schemes being considered. The problem, of course, is which ash samples and which arrangement of the different ash types will produce the most representative results--one of the same limitations of the laboratory effort.

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MEASUREMENT OF FUGITIVE EMISSIONS FROM INCO'S COPPER CLIFF SMELTER

PART III: REVERBERATORY FURNACES

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ABSTRACT

The Copper Cliff Smelter of Inco Metals Company, a major primary nickel and copper producer, is located in Ontario, Canada. The essential processing equipment consists of Multi-Hearth Roasters (∿30), Reverberatory Furnaces (6), Oxygen Flash Furnace and Peirce-Smith Converters (18). A comprehensive program to measure fugitive emissions of sulphur dioxide, sulphuric acid and particulates from the Smelter is being undertaken. This paper describes the reverberatory furnace section of this program.

Total fugitive emissions of sulphur dioxide, particulates and sulphuric acid from the reverb furnaces were measured as 15.2, 0.19, and 0.12 kg/Mg of bessemer matte equivalent respectively. Nearly 70% of the emissions occur during matte tapping. Slag skimming and furnace "puffing" contribute 20% and 3% respectively. Total fugitive sulphur dioxide emissions were found to be equal to those being emitted by all the converters (previously measured). However, most of the fugitive gas (∿90%) was captured at source by hood systems before release to atmosphere at roof level.

INTRODUCTION

A major program of measurement of fugitive emissions originating from the Copper Cliff Smelter of Inco Metals Company has been undertaken. The objectives of this program are: (a) identification of sources of fugitive emissions, (b) determination of sulphur dioxide, particulates and where possible, sulphuric acid concentrations in these emissions, (c) correlation of the fugitive emissions to the unit operations and the throughput of the Smelter and (d) to curtail the fugitive emissions.

Fugitive emissions originating from copper and nickel converters have been previously determined and reported.[1,2] This paper describes the findings pertinent to nickel reverberatory (reverb) furnace activities in the Smelter.

There are at present six nickel reverb furnaces in the Smelter of which usually three or four are operating at any one time. Four activities associated with reverb furnace operation produce significant quantities of fugitive emissions. These are matte tapping, slag skimming, furnace "puffing" and return of converter slag. Emissions from the last source had been previously estimated.[2] A general layout of a reverb furnace (No. 3) and associated hoods and vents is shown in Figure 1. Emissions arising during matte tapping are collected by the hoods above the matte tunnel and the matte launder, gathered in a fan-forced vent and exhausted to atmosphere via a "black ship" ventilator at roof elevation (∿50m). Similarly, slag skimming emissions are collected in another vent and released into a roof ventilator above the furnace and thence to the atmosphere. Emissions due to furnace "puffing" rise by convection and exit the building via the same roof ventilator.

Consequently, the measurement program was divided into two phases. Phase I consisted of the determination of sulphur dioxide, particulates and sulphuric acid in gases in the vents at the matte tunnel, and matte and slag launders, while Phase II involved measurement of the same in the roof ventilator. In the latter case measured emissions represented a combination of slag skimming and furnace "puffing" activities. Thus emissions due to slag skimming were measured twice which was considered useful to verify the results.

The measurement techniques were essentially the same as those employed in previous work[2], with the exception of a method for determining sulphuric acid. Previous attempts to measure sulphuric acid using an isopropanol capture system (EPA method 5) were unsuccessful. In the present study, sulphuric acid serosols were collected together with particulate matter on the same filter and were subsequently determined by chemical analysis.

EXPERIMENTAL

Phase I

This phase, as mentioned earlier, involved measurement of emissions in the vents from the matte tunnel, the matte launder and the slag launder.

Sampling points were installed at suitable locations in the three vents and gas velocities were determined with an S-type pitot. Volume flows were calculated and from velocity profiles, points representing average velocity were determined.

A sampling train as shown in Figure 2 was assembled. The gas sample was drawn continuously with a pump through a Balston filter* for particulate and sulphuric acid collection and was then directed to hydrogen peroxide solutions in impingers to caputre sulphur dioxide. Typically, sampling was done continuously for an eight hour period at the end of which the filter was removed, dried and weighed. Subsequent chemical analysis determined the sulphuric acid content on the filter. The hydrogen peroxide solution was titrated with sodium hydroxide (1N) and the quantity of sulphur dioxide was calculated. Using values of previously determined volume flows in the vents, total sulphur dioxide, particulate and sulphuric acid emissions for the eight hour period were determined. These were then expressed in terms of quantity per ladle of matte tapped or slag skimmed. In all, emissions were monitored for about 56 hours at the matte tunnel, 16 hours at the matte launder and 48 hours at the slag launder, covering the tapping of some 86 ladles (∿1700 Mg) of matte and the skimming of 83 ladles (∿2000 Mg) of slag.

Phase II

In this phase, emissions in the roof ventilator above the furnace were measured.

The roof ventilator consisted of a 5.9 m x 7.6 m section of transite stack of approximately 26 m in height and starting about 29 m above the furnace level. The ventilator was of the gravity flow type with non-uniform, low velocity gas flow profiles (see Figure 1).

The methods used in this phase were the same as those described in the previous study at nickel converters.[2] The sampling and analysis systems are shown in Figure 3 and 4 respectively. The sampling system was installed in the ventilator and was connected to the analysis system. The anemometer vane and thermocouple were fixed at positions representing average gas velocity and temperature and were connected to recorders.

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* Manufactured by Balston Filter Products, Lexington, Massachusetts, U.S.A.

Actual monitoring covered 19 shifts (~150 hours) divided into two sessions. Two technicians operated the analysis system on M-floor and one technician was located at the skimmer's platform. The latter recorded beginning and ending times for each ladle skimmed and transmitted this information via radio to the technician at the analysis station. Data was thus recorded on a per "event" basis where an "event" was defined as either a "skimming event" (representing emissions due to skimming and "puffing") or a "non-skimming event" (representing "puffing" emissions only).

Data recorded for each "event" included (a) activity, (b) duration of the activity (5-15 minutes), (c) sample gas volume (50-300 litres), (d) titrant (0.1N NaOH) volume, (0.1 to 10 ml), (e) gas velocity (4-5 m/s), and (f) gas temperature (10-20°C).

The staplex filter was changed every shift (eight hour period), dried overnight in a desiccator and weighed to obtain the combined weight of particulates and sulphuric acid (50-500 mg). The quantity of the acid was subsequently determined by chemical analysis. For each filter this data was recorded together with corresponding sample gas volume and the ventilator gas velocity and temperature.

Furnace draft was recorded at 15 minute intervals with a viewpoint of establishing a relationship between the draft and "puffing" emissions.

DATA ANALYSIS

Fugitive Emissions - Return Of Converter Slag

These emissions occur at the converter aisle end of the furnace and have been calculated in a manner similar to that used in the previous study of nickel converters.[2] It was assumed that the quantity of sulphur dioxide emitted during this process was the same as that when skimming a ladle of the furnace slag (12.1 kg/ladle from this study).

Phase I

Total fugitive emissions per ladle for matte tapping activity were calculated as the sum of the two separate components measured in the matte tunnel and launder respectively, both of which later combined and exhausted to the atmosphere. Total rate and average concentration of emissions were similarly derived. Fugitive sulphur dioxide emissions per ladle for slag skimming activitiy were also calculated. The latter were used for comparison with the measurements made in the roof ventilator.

Phase II

A computer program was developed to calculate for each shift both total sulphur dioxide emission and rate and concentration of the emission on a per "event" basis. A preliminary examination of results thus obtained indicated that emissions during a non-skimming "event" immediately following (1-3 minutes) a skimming "event" were invariably higher than during other non-skimming "events". This is shown in Figure 5. A closer examination of a typical "skimming event" as shown in Figure 6 revealed that a portion of the emissions actually attributable to the skimming activity was being counted as non-skimming or "puffing" emission. This carry over of emissions occured because a "skimming event" was considered terminated as soon as that activity stopped at the skimmer's platform, while the resultant change in emissions recorded at the analysis station (some 50 metres above the furnace) was not instantaneous.

Therefore, while total sulphur dioxide emissions per shift calculated by the computer were correct, distribution between skimming and "puffing" activities was erroneous. The following approach was used to calculate sulphur dioxide emissions from skimming and "puffing" activities:

1. Total SO_2 (kg) per shift obtained from computer printout - E_t
2. Average rate of emission (kg/min) during non-skimming "events" calculated from computer output, excluding "events" immediately following a skimming "event" - R_p
3. Emission due to "puffing" - E_p (kg) = R_p x time (minutes)
4. Emission due to skimming - E_s (kg) = $E_t - E_p$
5. Emission (kg) ladle = E_s/No. of Ladles

The particulate and sulphuric acid emissions were also calculated in terms of kilograms per ladle from the data obtained for each filter. Owing to very low concentrations of the particulates, the filter was changed approximately every eight hours. Therefore, the particulate and sulphuric acid emissions were not correlated with skimming and "puffing" activities separately, rather the results represented a combination of the two activities.

Finally, fugitive emissions were expressed in terms of unit production of bessemer matte* using relevant production data.

* Bessemer matte is the final output of the nickel circuit in the Smelter and contains Ni (50%), Cu (25%), and S (22%).

FUGITIVE SULPHUR DIOXIDE EMISSIONS

Total fugitive sulphur dioxide emissions from reverb furnaces were determined as 15.5 kg/Mg bessemer matte. Of these about 70% originated from matte tapping activity while slag skimming contributed 20% of the total. The remainder was attributed to furnace "puffing" and the process of returning of converter slag to the furnace. Results are shown in Table 1.

On a per ladle basis the sulphur dioxide emissions were 64 ± 12 kg during tapping and 12.1 ± 2.9 kg during skimming. The latter figure compared well with the value of 11.2 ± 4.2 kg obtained during Phase I.

The average rates of sulphur dioxide emissions during tapping, skimming and "puffing" were found to be 5.1, 1.4, and .06 kg/min., respectively. The average maximum rate of emission was therefore about 6.5 kg/min. The rate of "puffing" emissions showed no clear relationship with the furnace draft. However, the observed variation in the draft during the entire test was very small which presumably effected a change in sulphur dioxide emissions too small to be detected by the present technique.

The average sulphur dioxide concentration in the matte tapping emissions was 7400 mg/m^3 (2470 ppm) while that in the skimming emissions was 180 mg/m^3 (63 ppm). These were the concentrations in the emissions on entry to the atmosphere. The slag skimming emissions were diluted some twenty fold in the roof ventilator prior to release to the atmosphere, therefore, the concentration of sulphur dioxide was much lower. The average sulphur dioxide concentration in the "puffing" emissions was found to be 8 mg/m^3 (2.8 ppm).

FUGITIVE PARTICULATE EMISSIONS

Total patticulate emissions from reverb furnaces were 0.19 kg/Mg bessemer matte of which like sulphur dioxide, nearly 70% were attributable to matte tapping while the rest was contributed by slag skimming and "puffing" activities. Results are summarized in Table 2.

The average rate and concentration of particulate emission from matte tapping were .06 kg/min. and 81 mg/m^3 respectively. The mean combined rate of particulate emissions due to slag skimming and furnace "puffing" was .009 kg/min. The corresponding concentration was about 1.2 mg/m^3.

The main constituents of the particulates from matte tapping were sulphur (13%) and iron (5%) with copper and nickel being found in lower amounts. Particulates collected at the roof ventilator consisted mainly of iron (30%), copper (5%), and nickel (7%).

FUGITIVE SULPHURIC ACID EMISSIONS

Total sulphuric acid emissions from reverb furnaces were measured as 0.12 kg/Mg bessemer matte. Distribution of the emissions between matte tapping, slag skimming and "puffing" was much the same as for sulphur dioxide and particulates. Results are shown in Table 3.

Average rates and concentrations of the emissions during tapping were .04 kg/min. and 52 mg/m^3 respectively. Those attributable to slag skimming and "puffing" were .006 kg/min. and about 0.8 mg/m^3 respectively.

In general, sulphuric acid emissions were proportional to sulphur dioxide emitted. A plot indicating this relationship is shown in Figure 7.

Average sulphuric acid/sulphur dioxide ratio found in this study was about .010 which was similar to the value obtained during recent tests conducted on gases in the main chimney of the Smelter. This ratio was also fairly constant, the relative standard deviation being ± 25%, indicating that capture of sulphuric acid on the filter was probably quantitive. This was considered indirect support for the technique used for the measurement of sulphuric acid.

DISCUSSION

Precision and Accuracy

In previous studies of copper and nickel converters no attempt was made to determine the precision of the measurements. This was mainly due to the complexity of the converter operations, particularly in the case of nickel converters where interaction of emissions from two or more converters occured prior to reaching the measurement system. Consequently only a subjective estimate of precision was made, which was ± 10% for the copper converters and ± 90% for the nickel converters.[1,2]

In the present study on the nickel reverb furnace, the system was found to be more exact, with little or no interaction between emissions from different units and also with a good separation of emissions from various activities of the furnace. Thus precision (S.D./mean x 100) could be determined on per ladle basis.

For sulphur dioxide emissions this was found to be ± 20% for matte tapping and ± 24% for slag skimming. It should be emphasized that these values represented the overall fluctuations in the emissions, the precision of the measurement technique itself was considered to be much better.

In addition, slag skimming emissions were measured at two locations employing different techniques. The results are compared in Table 5. The sulphur dioxide emissions were measured as 11.2 kg/ladle in the vent from the slag launder (Phase I) which showed a good agreement with the value of 12.1 kg/ladle obtained in the roof ventilator (Phase II). Similarly the rate of sulphur dioxide emission of 1.5 kg/min. in the vent compared well with the rate of 1.4 kg/min. measured in the ventilator. Finally, the concentration of sulphur dioxide in the emissions was found to be 180 mg/m^3 in the ventilator. The same measured in the vent was 3080 mg/m^3 which was subsequently diluted 17 times in the roof ventilator to give a value of 181 mg/m^3. These comparisons were indicative of the high accuracy of the measurements.

GENERAL

Total sulphur dioxide fugitive emissions from reverb furnaces were quite similar to the total converter fugitive emissions. This is shown in Table 5. The particulate emissions from reverb furnaces were about the same as those from nickel converters while copper converters emitted much larger quantities of particulates. This was chiefly due to periodic addition of very fine flotation concentrate to the copper converters. An important difference between fugitive emissions from reverb furnaces and converters was that essentially all of the emissions from furnaces (∿90%) were captured at source by hoods before being released to the atmosphere. The converter fugitive emissions were uncaptured and tended to wander before leaving the building via roof ventilators. This difference was reflected in the quality of work room air in the two areas. The average eight hour reverb furnaces were found to be 0.9 ppm and 0.2 mg/m^3 respectively, compared to the corresponding average values of 2.5 ppm and 5.5 mg/m^3 found at the converters.

CONCLUSIONS

1. Measurement of fugitive emissions from nickel reverberatory furnaces has been successfully completed. The precision of the measurements was estimated as ± 20%.

2. Matte tapping activity was the major source of fugitive emissions, contributing about 70% of the total with slag skimming (20%) and other activities contributing the remainder.

3. Essentially all the fugitive emissions (∿90%) were captured at source before being emitted to the atmosphere.

4. Daily fugitive sulphur dioxide emissions from the reverb furnaces (15.5 Mg) were similar to the total daily converter fugitive emissions (13.8 Mg).

5. Judged by the criterion of the constancy of sulphuric acid/sulphur dioxide ratio, the present technique of capturing the acid by filtration seemed to be satisfactory.

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2. "Measurement of Sulphur Dioxide and Particulate Fugitive Emissions From the Nickel and Copper Converter Operations at Inco's Copper Cliff Smelter", A.D. Church, C. Landolt and F. Boniakowski; presented at the 18th Annual Conference of Metallurgists sponsored by Canadian Institute of Metallurgy in Sudbury, Ontario, August 1979.

Figure 1

Vent Arrangements at Nº 3 Reverb Furnace

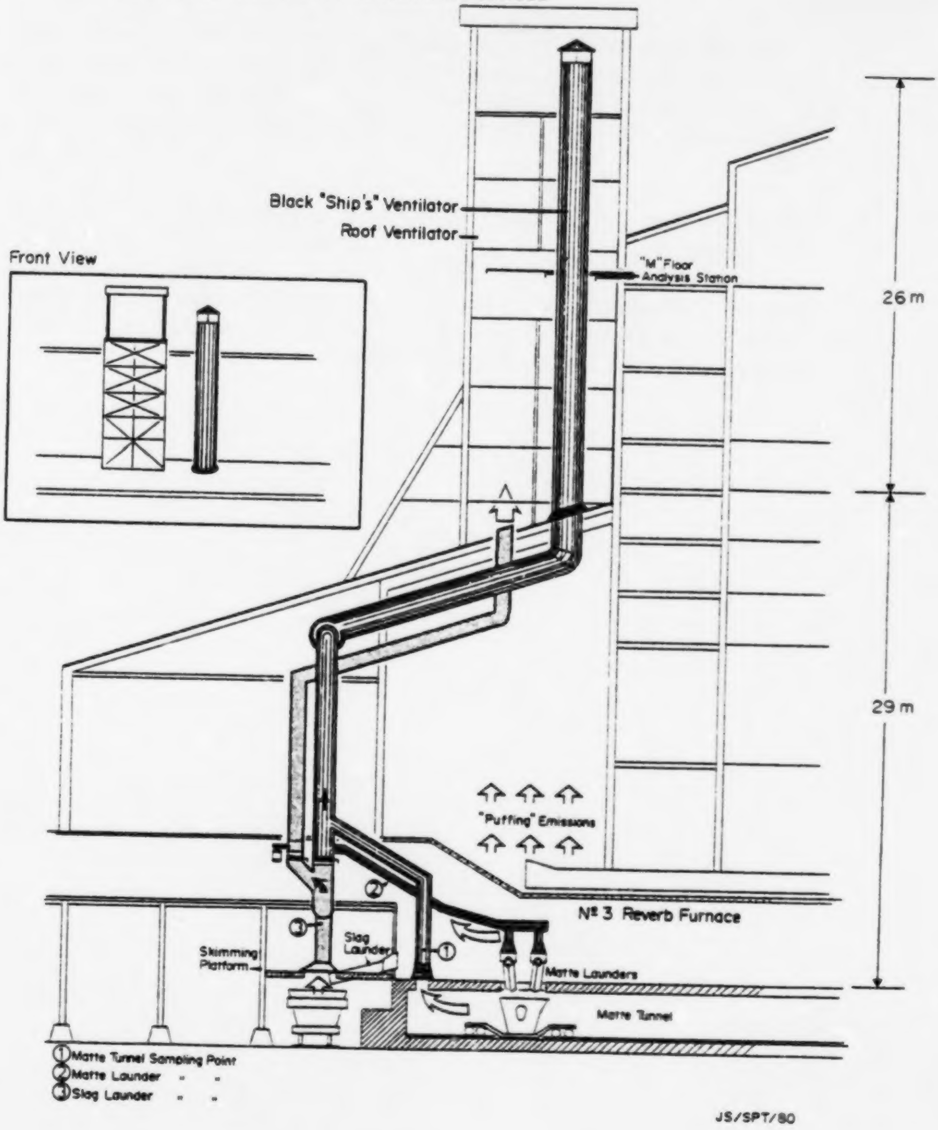

Black "Ship's" Ventilator
Roof Ventilator
Front View
"M" Floor Analysis Station
26 m
29 m
"Puffing" Emissions
Nº 3 Reverb Furnace
②
③
①
Skimming Platform
Slag Launder
Matte Launders
Matte Tunnel
① Matte Tunnel Sampling Point
② Matte Launder " "
③ Slag Launder " "
JS/SPT/80

Figure 2
Sampling Train Used in Phase I

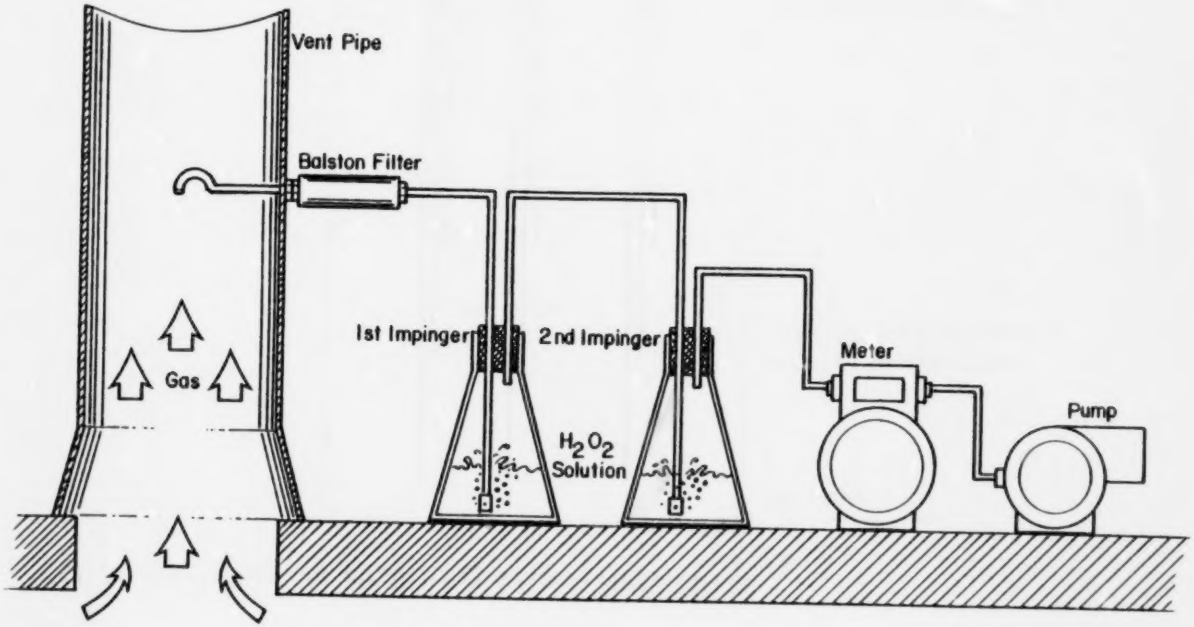

Vent Pipe
Balston Filter
Gas
1st Impinger
2nd Impinger
H_2O_2 Solution
Meter
Pump

Figure 3

SO2 and particulate monitoring system. (Phase II)

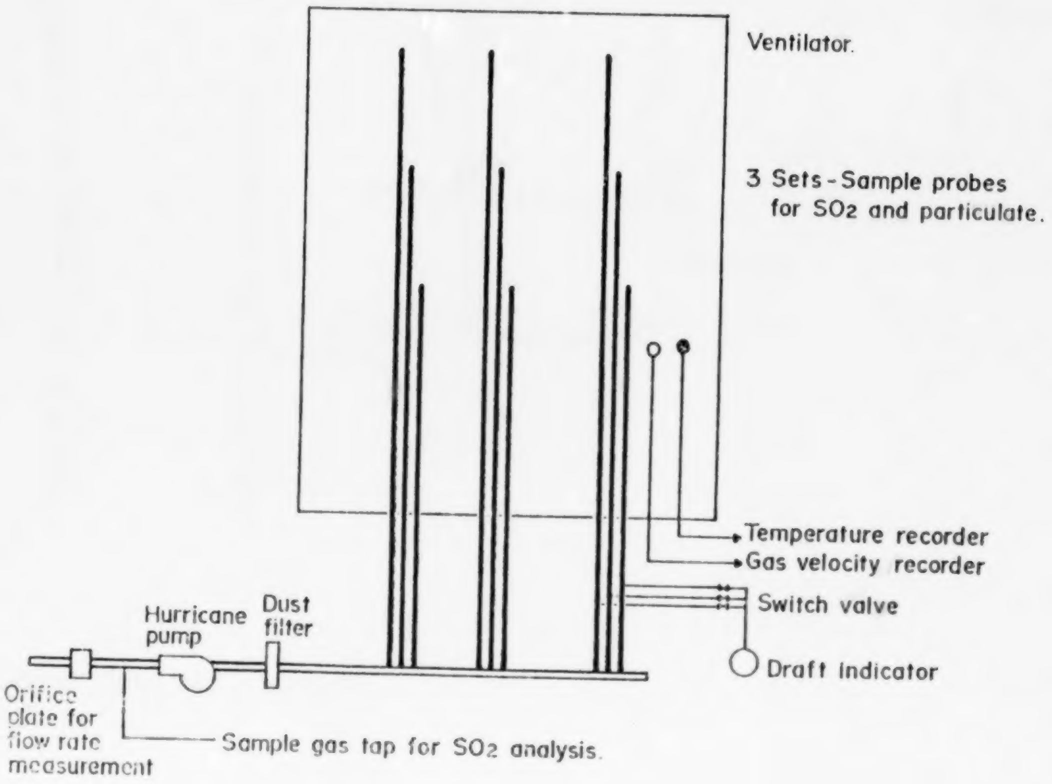
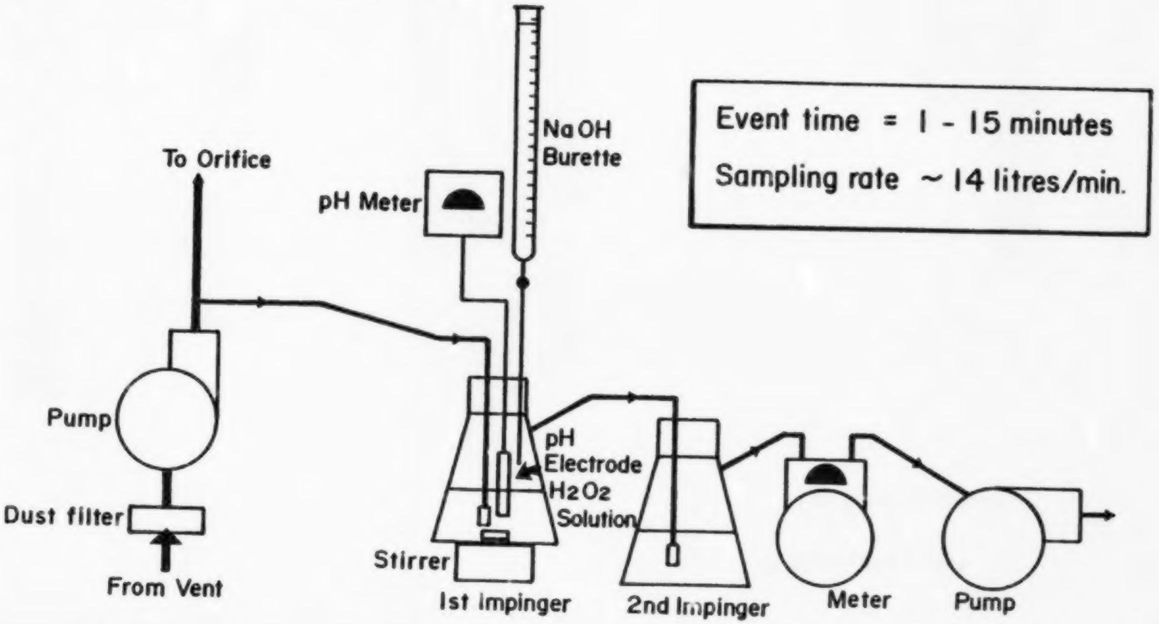

Ventilator.
3 Sets - Sample probes for SO_2 and particulate.
Temperature recorder
Gas velocity recorder
Switch valve
Draft indicator
Hurricane pump
Dust filter
Orifice plate for flow rate measurement
Sample gas tap for SO_2 analysis.

Figure 4

Analysis System (Phase II)



Event time = 1 - 15 minutes

Sampling rate ~ 14 litres/min.

To Orifice
pH Meter
NaOH
Burette
Pump
Dust filter
From Vent
pH
Electrode
H_2O_2
Solution
Stirrer
1st Impinger
2nd Impinger
Meter
Pump

Figure 5

SO_2 Emissions during different events

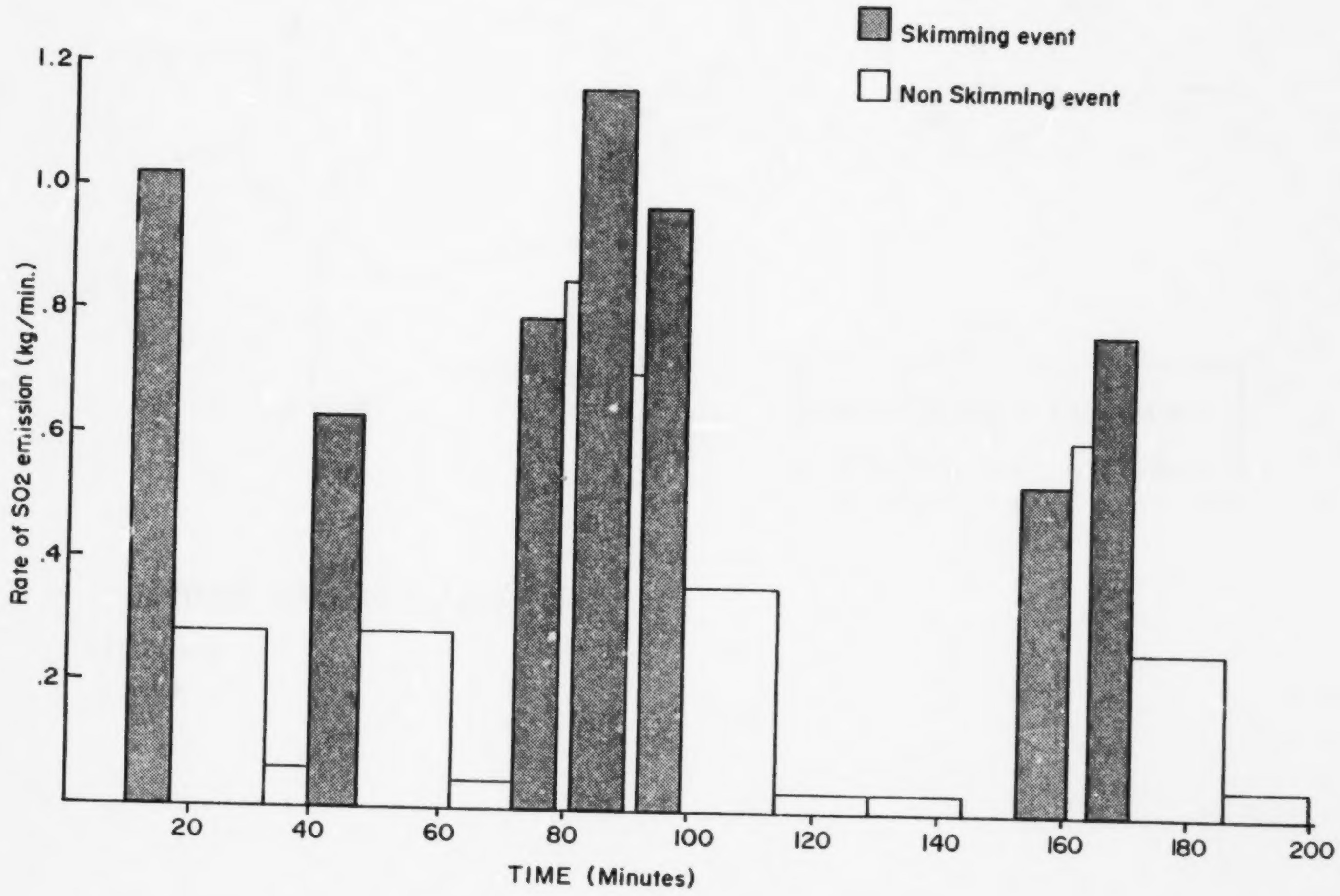
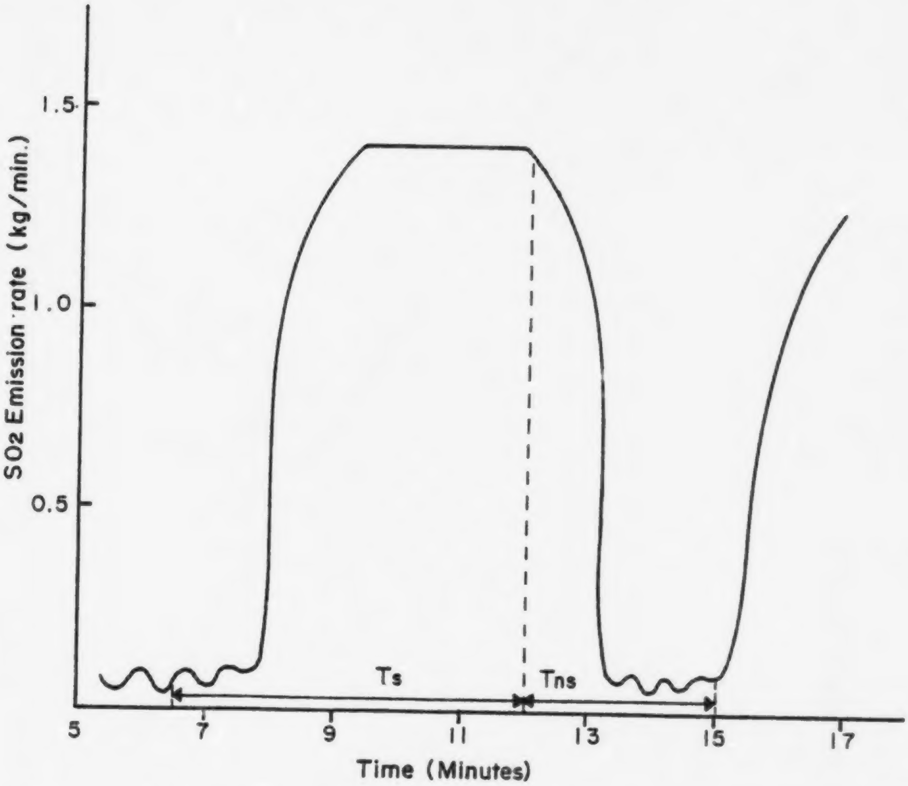


Figure 6

SO2 Emissions during Typical Skimming Event.



Ts = Recorded duration of a SKIMMING EVENT

Tns = " " " NON SKIMMING EVENT

Figure 7

Sulphur dioxide vs. Sulphuric acid.

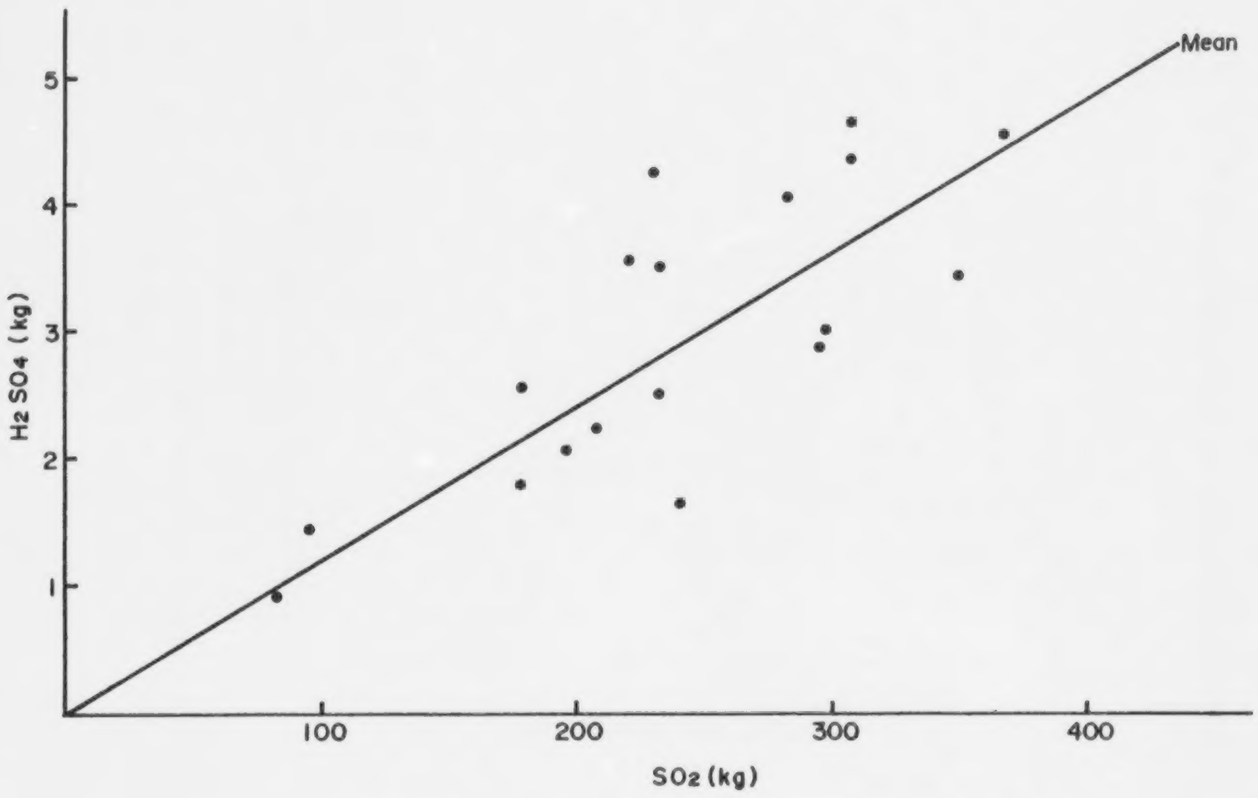


TABLE 1

Fugitive SO_2 Emissions From Reverb Furnaces

Activity	SO_2 (kg/Mg B.M.)***	Emission Rate (kg/min)	Concentration (mg/m^3)
Matte Tapping	10.80	5.08	7,390
Slag Skimming	3.07	1.41	180
Puffing	0.41	0.06	8
Return Of Converter Slag	1.20	N/A*	N/A*
Total	15.5	6.55**	-

* - Not Available
** - Maximum
*** - Bessemer Matte

TABLE 2

Fugitive Particulate Emissions From Reverb Furnaces

Activity	Particulates (kg/Mg B.M.)*	Emission Rate (kg/min)	Concentration (mg/m^3)
Matte Tapping	.119	.057	81
Slag Skimming + Puffing	.068	.009	1.2
Total	.187	.066**	-

* - Bessemer Matte
** - Maximum

TABLE 3

Fugitive Sulphuric Acid Emissions From Reverb Furnaces

Activity	H_2SO_4 (kg/Mg B.M.)*	Emission Rate (kg/min)	Concentration (mg/m^3)
Matte Tapping	0.077	0.037	52
Slag Skimming + Puffing	0.043	0.006	0.8
Total	0.120	0.043**	-

* - Bessemer Matte
** - Maximum

TABLE 4

Comparison of Slag Skimming Emissions Measured at Two Locations

Location	SO_2/Ladle	kg/min	mg/m^3
Vent From Slag Launder (Phase I)	11.2 ± 4.2	1.5 ± 0.4	181* ± 55
Roof Ventilator (Phase II)	12.1 ± 2.8	1.4 ± 0.3	180 ± 51

* Corrected for dilution in the roof ventilator.

TABLE 5

Comparison of Fugitive Emissions From Converter and Reverb Furnaces

Source	SO_2 (Mg/Day)	Particulates (Mg/Day)	Sulphuric Acid (Mg/Day)
Copper Converters	10.6	1.1	N/A *
Nickel Converters	3.2	0.2	N/A *
Total Converters	13.8	1.3	N/A
Nickel Reverb Furnaces	15.5	0.2	0.1

* Not Available

CONTROL OF FUGITIVE EMISSIONS FROM COAL STORAGE PILES

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ABSTRACT

The Steel Company of Canada is a fully integrated steel producer with its primary steelmaking facilities located in Hamilton, Ontario. The basic end of this operation consists of four coke batteries, four blast furnaces, one OH shop and one BOF shop.

During the period December to March when the Great Lakes and the St. Lawrence Seaway are ice bound, shipping of raw materials is curtailed and both iron ore pellets and coal must be stockpiled to allow for continuous operations. At any one time approximately 83 acres of land is covered by up to 7 distinct coals or coal blends. Because the percentage of fines can be as high as 15 percent, coal dust particle movement by the wind can be severe.

MHTR Engineering was retained to examine the situation and to recommend measures to alleviate the existing conditions. This study was based on constructing models of the site and testing them in a wind simulator to determine the problem areas and to test the remedial solutions.

The study indicated that orientation and shaping of the coal piles were key factors in controlling the turbulence which resulted in particle movement.

Suggested solutions which have been implemented have significantly reduced the problems associated with storage of coal in open sites.

CONTROL OF FUGITIVE EMISSIONS FROM COAL STORAGE PILES

Over the past few years environmental legislation has focused on control of point sources of industrial emissions. While this control has led to improvements in the levels of tsp in the ambient environment there has been a greater recognition that fugitive emissions are also significant contributors to urban dustfall levels. In an integrated steel plant a large source of potential fugitive emissions is raw materials storage piles.

One of the world's major integrated steel companies, Stelco is ranked No 1 in Canada, and No 9 in North America. Steel production at its primary facilities in Hamilton, Ontario, at the western end of Lake Ontario, some 60 miles northwest of Buffalo, New York, is approximately 6 million ingot tons per year. When a greenfield expansion program, now in progress, is completed, it is estimated that the Company's production will eventually double to 12 million ingot tons per year. This greenfield site is located on the shore of Lake Erie, opposite Erie, Pennsylvania.

Three basic materials — iron ore, coal and limestone — are needed to make steel. Coal and iron ore are most economically shipped by water transport to Stelco's docks at Hamilton. These facilities handle over 370 ships each year. Since it takes 1 ton of iron ore, ½ ton of coal and miscellaneous flux materials to produce 1 ton of steel, a company the size of Stelco must handle approximately 10 million tons of bulk raw materials each year at its Hamilton plant. At any one time the coal storage piles cover approximately 83 acres of land (roughly 1/10 of the total area covered by these operations) and because up to 7 different coals or coal blends are utilized, the coal storage area is comprised of several separate piles rather than one large continuous pile.

As mentioned earlier the majority of raw materials are shipped through the Great Lakes waterway system. Coal from Kentucky and West Virginia must cross Lake Erie and move through the Welland Canal system, bypassing Niagara Falls, in order to reach the facilities at Hamilton. However, due to the severe Canadian climate this method of transport is not available from December to March each year. As a consequence the storage piles are considerably larger than those kept by most United States steel companies. Allowing for the four months that the waterway is impassable and a one-month safety factor to ensure a continuation of operations should strikes occur within any of the unions involved in shipping, shore handling and mining, there is a requirement to store approximately five months' supply of raw materials at the end of every shipping season.

The coal arrives at Hamilton in self-unloading vessels. A conveyor deposits the coal in a conical pile on the dock. Water is continually sprayed on the coal to limit dust blow-off during the unloading process. A bulldozer is used to level this conical pile permitting large mobile scrapers to transfer the coal to the storage piles, which may be up to 1100 ft in length, and deposit the new coal in thin layers. This layering process is used to partially blend the old and new coals. During the passage of the scraper a great deal of coal dust is released into the air. A similar process in reverse is used during the ex-stocking process when the coal is removed from the storage piles and taken to the Coke Ovens.

In periods of elevated wind speed fugitive emissions may be generated at the following times:

- when the coal drops from the conveyor to the conical pile,
- general wind erosion from the conical pile,
- during the period the scraper is traveling over the storage piles or the arterial roads, and
- general wind erosion from the long-term storage piles themselves.

Several of these problem areas were recognized many years ago and solutions were implemented to control the problems. During unloading:

- water sprays were directed into the unloading coal, stream and conical piles,
- the free-fall height of the coal was minimized by lowering the conveyor as much as possible, and
- a protective enclosure was attached to the conveyor to minimize wind access to the falling stream of coal.

While these precautions were satisfactory under normal atmospheric conditions with extremely high winds they did not suffice and unloading operations had to be terminated.

In order to minimize dusting while the scrapers move along the roads and storage piles tanker trucks were used to spray water in the summer. In the winter these same trucks were used to spray waste oil onto the roadways. The storage piles were coated with a binding agent near the end of the shipping season. This was only a limited success. Some of the problems associated with wind loss from storage piles were reduced by the above measures. A key step, however, was the reduction of the number of storage piles to six. This allowed for both an orderly layout of the piles and contouring of the piles. A final step in these early efforts was the adoption of a procedure whereby coal was removed only from the end of the storage pile during winter months. This eliminated disturbance of the top surface of the pile during the winter when water spraying could not be utilized.

While these steps were successful to some degree, incidents of wind erosion of the storage piles resulting in blowing coal dust continued to occur especially during the extreme conditions experienced in winter. At this time a consultant (Morrison, Hershfield, Theakston and Rowan), who had considerable experience in the study of wind-blown materials as well as wind tunnel and water flume testing was retained. The problem as presented to the consultant was to determine the areas of coal loss from the storage piles and to recommend methods for control. A second phase involved a study of surface binders to determine the best product to be used to coat the storage piles to carry through the winter period.

On the first phase of the study the technique used consisted of a model analysis by employing an open channel water flume especially designed for the study of particle movement and control. This flume is 40 ft long, 4 ft wide and 18in deep. By varying the depth of water a variety of wind velocity conditions can be simulated. Particles of coal were simulated by silica sand and wind movement was observed by injecting a dye into the flowing water to indicate turbulence and direction.

A model was constructed of the complete site including the terrain, buildings, conveyors, stacks, ore piles, coal piles, the unloading docks and surrounding water area as well as separate models of the coal piles. The model of the site was used to determine the general flow pattern of the wind and the effect of the various components comprising the site. The models of the coal piles were used in assessing, in detail, the effect of orientation and shape of the piles.

Water Flume Test Results

Since wind direction is an important factor in the movement and entrainment of coal particles, the water flume allows for the rotation of the model to simulate changes in wind direction. In the Hamilton region south-west and westerly winds are predominant. In all cases coal piles transverse to the wind direction and even at a slight angle to the wind created turbulence on the lee side of the pile. With consecutive piles a channel was created to carry the particles at a higher velocity, due to the venturi action, to the leeward side of the site. Coal piles located in line with the wind eliminated the turbulence. Based on this result a decision was made to reorient the axis of the storage piles so that they would be in line with the prevailing wind. This required changing the entire field arrangement and was carried out over one shipping season.

Shaping of the coal piles is an important factor in reducing turbulence due to sharp edges and scour action. Reduction of sideslopes will reduce the scouring at the top of the slopes and the optimum slope is 1:7. However, steeper slopes will have progressively detrimental effects from 1:7 sideslopes to 1:1 sideslopes.

While we were able to achieve the ideal slope at the leading edge of the pile which faces the prevailing wind using that flatter slope for all sides would have required a coal storage area many times the size available. We utilized a rounded crown which was suggested as an alternative shaping program where a 1:7 optimum slope is not feasible.

When more than one coal pile with 1:1 sideslopes (angle of repose) is used, turbulence is pronounced on the leeward side and in the channels formed by adjacent piling. The 1:7 sideslopes used for optimizing wind flow patterns eliminates the turbulence and eddy action.

An alternative recommendation to the 1:7 sideslope consists of rounded sideslopes or the employment of a porous fence along the windward portion and top of the pile. These alternatives are proposed only where space limitations require a 1:1 sideslope.

The leeward end of the piles, where coal is ex-stocked in the winter time, is an area of particular concern. The flume studies indicated that the installation of a 12-ft high porous fence on top of the pile, approximately 150 ft from the leeward edge, would be effective in reducing turbulence. As an alternative, three 4-ft high snow fences placed 60 ft apart parallel to each other in line, and parallel to the leeward face, were shown to be equivalent to one 12-ft high fence. In fact, both of these methods were tried and both proved to be effective and the combination of both is used in the field.

The final recommendation of the study was to install a snow fence near the leeward edge of the entire field to catch dust which may be entrained along the ground surface. This was done and has proved to be effective in controlling dust not caught in other ways.

All these recommendations have been acted on and the practices are in continuous use in the coal storage fields. The coal piles were reoriented and reshaped as recommended by the consultants.

Wind Tunnel Test Results

The use of binding agents applied to coal piles is a current practice in reducing the movement of coal particles from storage piles. In the second phase of the study, samples of six types of coal used by Stelco were compacted in small boxes to simulate a coal pile with a leading edge to the wind. They were coated with various combinations of six different binders and placed in the wind tunnel. These tests were supplemented by small sample piles in the field at Stelco to test the weatherability of the various binding agents.

As a general rule the thickness of the crust formed was found to be a measure of the effectiveness of the binding agent in reducing particulate movement.

The study was narrowed to two binding agents plus waste oil which is generated internally at the plant. All three were tried in test applications on the actual piles for a complete winter season. We have decided to use an asphaltic product supplied by Flintcote as the main binding agent to be applied to the piles at the end of each shipping season and to carry us through to the spring. Waste oil is used for the active area at the end of the pile and for road dust control during the winter time.

The binding agents are to be applied in November and again at the end of the shipping season to ensure that snowfall does not prevent us from getting the agent directly on the surface before the main onslaught of winter. During the summer season, water is the main dust control agent on the piles and on the roads.

An important feature of our control program has been the issuance of a detailed list of operating instructions for the coal field. This involves regular attention to a wind recording device as well as regular contact with the local Weather Office for wind prediction on each shift. Action to be taken on prediction or recording of increased wind speeds is clearly recorded.

By these actions we have recognized that continuous attention to a remedial program designed to combat fugitive emissions from coal storage fields is required. This prolonged study has shown that a combination of both physical and chemical methods based on a scientific approach can result in significant reductions in dust emissions from bulk storage sites.

USE OF ROOF MOUNTED TYPE ESP'S IN IRON AND STEEL INDUSTRIES IN JAPAN

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SUMMARY

The first ROOF MOUNTED TYPE ESP (REP) in Japan was installed in March, 1972 at a steel converter shop (80 tons x 3 units) in KOBE WORKS of KOBE STEEL CORPORATION, LTD. by the hand of SUMITOMO HEAVY INDUSTRIES, LTD.(SHI) after a cooperative developmental effort made by both companies. This first REP showed a very successful result, lowering the dust loading from 0.246 (g/Nm^3) at its inlet down to 0.032 (g/Nm^3) at its outlet (collection efficieny: 87 %). Thus, it proved to be one of the most effective means of fugitive emission control in the iron and steel industries. The first aim of this development was to solve the problem of a limited installation site. However, it has become clear after the start of its operation that this solution using a thermal lift of hot dirty gas itself has several other large advantages compared to an alternative solution using forced suction and bag-house.

The first of these additional advantages is its inherent extremely energy saving character resulted by elimination of a large capacity suction fan. The total power consumption is only 5 - 10 % of that needed for the system with forced suction and bag-house, even estimated from a very moderate assumption that the dirty gas volume to be handled is the same for both cases. Actually, however, the gas volume to be treated by REP is only the net gas volume of dirty gas automatically subjecting to a thermal lift. Whereas, in the latter case, a large quantity of ambient air is inevitably mixed to the hot dirty gas, so that the total gas volume to be suctioned becomes enormous, amounting to 1.5 - 2.5 times the actual dirty gas volume.

The second of additional advantages is its noiseless character also due to the elimination of the suction fan. As a result of these remarkable merits REP has been very positively accepted by the iron and steel industries in Japan for fugitive emission control.

The major manufacturer of REP is SUMITOMO HEAVY INDUSTRIES, LTD.(SHI), but SUMITOMO METAL & MINING CO., LTD.(SMM), HITACHI PLANT ENGINEERING & CONSTRUCTION CO., LTD.(HPC), and CHIYODA CHEMICAL ENGINEERING CO., LTD. are also sharing to the REP market. The total number of REP's installed by March 1980 is at least 38 units with 9 units for converter shops, 7 units for casting floors of blast furnaces, and 22 units for electric furnaces of various types.

In this paper is reported the present status of the ROOF MOUNTED TYPE ESP's for fugitive emission control in the iron and steel industries in Japan.

1. Introduction

The ROOF MONTED TYPE ESP (REP: ref. (1) - (7)) has aquired, since its first installation in March, 1972 at a steel converter shop (3 units x 80 tons; KOBE WORKS of KOBE STEEL CORPORATION, LTD.), an established position in the japanese iron and steel industries for the control of fugitive emissions at various workshops including converter shops, catsing floors of blast furnaces, and electric furnaces. A light-weight ESP is mounted on top of the roof of a workshop, and the dirty hot gas emited from its sources is passed through this ESP by the action of its thermal draft without the aid of a suction fan. The first aim of considering this technology was to solve the problem of a limited site for installation of a conventional dust collecting facility. However, after its start of operation a quite remarkable advantage of REP in its inherent energy saving character has become clear. This is because it does not use a large capacity induced fan which, otherweise, has to suction the hot dirty gas plus a substantial quantity of surrounding air against a high pressure drop of a gas duct system (150 - 250 mm H_2O) and a bag filter (150 - 200 mm H_2O). The total gas volume to be handled in the forced suction system amounts to as high as 1.5 - 2.5 times that of the actual dirty gas (5). In addition, its noiseless feature resulted by elimination of the fan also provides a large merit.

As a result REP's are being used in increasing number in the iron and steel industries in Japan, amounting to as many as at least 38 units in total at the end of March, 1980: 9 units for converter shops, 7 units for casting floors of blast furnaces, and 22 units for electric furnaces of different kinds. The largest share-holder among the manufacturers of REP in Japan is SUMITOMO HEAVY INDUSTRIES, LTD.(SHI), whereas SUMITOMO METAL & MINING CO., LTD.(SMM), HITACHI PLANT ENGINEERING & CONSTRUCTION CO., LTD.(HPC) and CHIYODA CHEMICAL ENGINEERING CO., LTD. are also manufacturing REP's.

In this paper is reported the present status of the ROOF MOUNTED TYPE ESP's in Japan as applied in the iron and steel industries, including its construction, design problems, application fields, and its specific advantages, together with its operation data.

2. Construction

Fig. 1 illustrates a system of the fugitive emission control equipped with REP. There are slight differences in the construction of REP depending upon the difference in manufacturer's design concept and specific conditions of indivisual applications.

Figs. 2 illustrate the construction of SHI-type REP, and Fig. 3 shows its photograph taken from outside. A light-weight ESP is mounted on top of the roof of a workshop above the emission sources.

The collecting electrodes are out of thin stainless-steel plates, and the discharge electrodes are stainless-steel wires or round piano-wires supported by metal frames. The use of the frame construction provides advantages in light-weight and ease of centering. No thermal deformation occurs in this particular case as the gas temperature at the precipitator inlet is below 80 (deg C) (typically 40 - 60 deg C).

The whole electrode system is mounted inside a light-weight housing having no roof on its top. The shell of the housing is out of a special laminated plate consisting of a thin steel plate covered with plastic layers so that sufficient durability can be obtained against corrosion and weathering in spite of its small thickness.

The precipitator is of a semi-wet type with both collecting and discharge electrodes being intermittently cleaned by water spray. The whole REP unit is devided into a number of blocks, and washing is made block by block. Each block is washed 1 - 4 times a day, each time for 10 minutes with a water feed rate of 0.1 - 0.6 (m^3/min) (typically 0.4 m^3/min). So, the water feed rate needed is independent of REP capacity, and the total quantity of spray water to be supplied per day is very small, and given by

$$Qw = (0.1 - 0.6\ m^3/min) \times (10\ min) \times Nb \times Nw \qquad (m^3/d) \qquad (1)$$

where Nb = number of blocks, and Nw = number of washing per day. The use of this semi-wet design provides the advantages such that both the back discharge due to high resistivity dust and the dust reentrainment due to mechanical rapping are effectively avoided, that the noise and vibration problem in rapping operation is solved, and that elimination of the rapping system with many moving parts contributes to the light-weight scheme and ease in maintenance. In addition, the semi-wet scheme combined with the open housing construction contributes much to avoid a danger of explosion to be caused by coal dust and carbon monooxide.

The slurry is collected by a louver-shaped hopper located under each block, and fed through troughs to a conventional water treatment system, as indicated in Fig. 4. A portion of clear water is reused for spraying after pH-adjustment.

The hot dirty gas from the emission sources rises with its thermal lift up to the top of the workshop, and enters through the louver-hoppers into the collection field of each block of REP. The louver-hoppers serve as a gas distributer to equalize the gas velocity. The gas flows upward vertically through the collecting ducts, and is emited directly into open air from the top of REP.

The insulators supporting the frames of discharge electrodes are encased in the insulator boxes located on top of the REP housing, and clean air is purged into the boxes to prevent contamination of the insulators.

A high voltage power-pack with automatic voltage control is also mounted on top of the roof of the workshop.

Table 1 indicates an example of the design data of a SHI-type REP installed at a converter plant.

Figs. 5 shows a photograph of the SMM-type REP. In the SMM design, the hot dirty gas is at first gathered in a monitor, and, then, fed horizontally to REP mounted on top of the workshop roof adjacent to the monitor (Fig. 6). A number of low-power roof-fans are installed at the outlet of the SMM-type REP to suction the gas horizontally through its collection field. Both the dry-type and wet-type REP's are manufactured by SMM.

The details of the constructions of REP's of SMM and other manufactureres are not much ifferent from that of SHI, so that the further descriptions of each design are omitted.

3. Design Problems

There are several problems to be carefully considered in the planning and design of REP. These are the estimation of gas volume to be handled by REP, the properties of dust to be collected, the location of REP with respect to the number and position of emission sources, and prediction of wind.

3-1) Calculation of Gas Volume:

The ascending speed of hot dirty gas from emssion sources lowers with height because of the decrease in its temperature due to mixing with ambient air. Its final speed at the inlet of REP depends upon the roof height, building volume and shape of the workshop as well as the number, capacity and operating conditions of the emission sources. As a result, an accurate estimation of the gas volume to be handled by REP is extremely difficult, and requires much experience.

In the case when REP is to be installed on an existing workshop, it is imperative to directly measure the gas volume in advance by measureing velocity distribution of gas at each monitor under various operating conditions. The measurement of dust loading must also be performed at the monitor.

In the case when REP is to be installed on a new plant, the following theoretical gas volume, Qz, used for design of a canopy hood provides a clue for the gas volume estimation of REP (see Fig. 7):

$$Qz = 1.95 \times Z^{3/2} \times (H')^{1/3} \qquad (m^3/min) \qquad (2)$$

$$H' = (1.45/60) \times As \times T^{4/3} \qquad (kcal/min) \qquad (3)$$

where Z = height of REP inlet from provisional position of heat source (m), H' = heat transmission of convection current from heat source (kcal/min), As = surface area of heat source = $(\pi/4) \times Do^2$ (m^2), T = temperature difference between heat source and ambient (deg C).

The actual gas volume to be handled, Q, can be estimated by multiplying a correction factor, K, as:

$$Q = K \times Qz \qquad (m^3/min) \qquad (4)$$

The correction factor should be selected in the range of K = 1.5 - 2.5 from the experience at the similar installations.

Fig. 7 is a chart for estimation of Qz as a function of H and Do for the case when Z = H + 2 Do (4).

3-2) Dust Properties:

The mass-loading, particle size distribution, chemical composition, and electrical resistivity of the dust to be handled by REP must be carefully studied. The inlet mass-loading of dust determines the quantity and frequency of water spraying and the capacity of water treatment system. In most cases, however, the inlet mass-loading of dust hardly exceeds the level of 1 (g/Nm^3).

The frequency of water spraying must be raised for fine particles in order to avoid the dust reentrainment. Table 2 gives the examples of the particle size distribution of converter dusts in Japan.

The chemical composition of dust may affect the design of pH-adjustment system for slurry treatment, the corrosion of electrodes, hoppers and a piping system of REP, and probably the electrical resistivity of dust. Table 3 provides the chemical composition of the dusts indicated in Table 2.

The electrical resistivity of dust may become very high at 60 - 90 (deg C) to be encountered at the inlet of REP, as shown in Table 4. Then, a severe back discharge may occur in the collection field of REP when the quantity and frequency of water spraying is insufficient or the water spray system fails.

3-3) Location of REP:

From an economical point of view REP should be located only at an area at which dirty hot gas arrives. The location of REP must be determined, considering the thermal current of the dirty gas, its diffusion and the effect of wind.

4. Applications

4-1) Converter Shop

In this application the dirty gas volume is very large, so that its total quantity is handled only by REP. The fluctuations in gas temperature, gas velocity and dust loading at the inlet of REP are very large in this application. Table 5 gives some of the design and operation data in this application.

4-2) Casting Floor of Blast furnace

Again in this application the whole dirty gas is handled solely by REP because of its very large volume.

4-3) Electric Furnace

In this application REP is used either alone or in combination with monitors, depending upon the workshop conditions. The fluctuations in gas temperature, gas velocity and dust loading at the REP inlet are also very large. Table 6 provides again some of the design and operation data in this application.

5. Advantages of ROOF MOUNTED TYPE ESP's

REP's have the following inherent advantages:

(1) Saving of installation site.

(2) Stable operation and high collection performance.:

This is resulted by the semi-wet operation scheme where no back discharge and dust reentrainment take place.

(3) Low installation costs:

The installation costs may become rather lower than the alternative emission control system using forced suction and bag-house because of the simple light-weight construction of REP as well as the elimination of a large suction fan and a gas duct system.

(3) Very low power consumption:

The total electric power consumption of REP is only 5 - 10 % of that needed for the system using forced suction and bag-house. This is resulted by the eliminations of a large induced fan which has to suction a large gas volume against the pressure drops at canopy hoods, gas duct (150 - 250 mm H_2O) and filter bags (150 - 200 mm H_2O). The pressure drop of REP is almost the same as that of monitors. This figure of energy saving is a very moderate estimation assuming the gas volume to be the same for both cases. However, the actual gas volume to be handled in the latter case amounts to 1.5 - 2.5 times that of REP which selectively handles the hot dirty gas ascending by its inherent thermal lift.

(4) Operation without noise and vibrations.

(5) Low maintenance costs:

The maintence costs of REP are very small because it does not require the exchange of bags and moving parts, and its water consumption is also small. The amount of water feed rate needed for electrode spraying is only 0.1 - 0.6 m^3/min, and the used water is recycled after slurry treatment. As a result the amont of water for replenishment is little. In addition, the maintenance work is hardly needed because of its simple construction without moving parts.

6. Energy Saving Feature of ROOF MOUNTED TYPE ESP's

As the contribution of REP to enery saving is quite remarkable, it deserves a special investigation. A comparison is made of the power consumption for the respective applications between a REP system and a conventional system with forced suction and bag-house (7). The power consumption of the REP systems is taken from the practical operation data, whereas those of the systems with forced suction and bag-house are calculated based on the same gas volume as previously described. Tables 7 8 and 9 show respectively such a comparison in the applications for a converter shop, a casting floor of blast furnace and an electric furnace. It may be well understood that the contribution of REP to energy saving must be given a special attention.

The case studies of comparison are further made between the two systems, considering all the power consumption needed not only for operation of each dust collecting equipment, but also for production of all the materials necessary to construct each equipment (7). The calculated result for a standard 30 ton/ch. electric furnace is given in Table 10 , whereas that for a standard 160 ton/ch. converter in Table 11 . These results reveal that the saving of energy resulted by the use of REP amounts in ten years to as high as 188.8 x 10^9 (kcal) in the former case and 350.4 x 10^9 (kcal) in the latter case. Based on these data the study is extended to all the electric furnaces and converters existing in Japan in December, 1976 (Table 12). The saving to be obtained by using REP's in ten years in all of the electric furnaces will amount to as high as 68.5 x 10^{12} (kcal), while that in the converters to 32.2 x 10^{12} (kcal). This energy saving corresponds to ca. 1 million tons of crude oil per year.

7. Conclusion

The present status of ROOF MOUNTED TYPE ESP's in Japanese iron and steel industries is described. The conclusions of this parer are as follows:

(1) REP's have aquired an established position in the Japanese iron and steel industries.

(2) REP's have a number of inherent advantages over a system with forced suction and bag-house. These are (a) saving in installation site, (b) stable operation and high collection performance, (c) very small power consumption, (d) low initial and maintenance costs, (e) operation without noise and vibration, etc.

It is likely that ROOF MOUNTED TYPE ESP's will be more extensively used in future in Japan, not only in the iron and steel industries but also in the other industrial fields, primarily because of its very remarkable merit of energy saving.

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Table 1 Design Data of SHI-Type REP for Converter

1. Dimension	4800 mm height x 6800 mm width x 50000 mm length
2. Casing	# 24 color steel plate
3. Collecting Electrodes	stainless-steel plate
4. Discharge Electrodes	stainless-steel wires supported by steel frames
5. Power Consumption	high voltage power pack: 90 kw motors, etc.: 11 kw
6. Water Feed Rate	0.6 m^3/min. (intermittent cleaning)
7. Gas Volume	17100 - 27800 m^3/min.
8. Gas Temperature	35 deg C
9. Inlet Dust Loading	0.270 g/Nm3
10. Outlet Dust Loading	0.047 g/Nm3

Table 2 Example of Particle Size Distribution of Converter Dust

	∼ 10 μm	10 ∼ 20 μm	20 ∼ 50 μm	50 μm ∼	true specific gravity
A Co.	15.5	19.5	50	11	3.49
B Co.	4	11	53	32	4.27
C Co.	13.5	30.5	42.0	14.0	3.94

Table 3 Results of Chemical Analysis of Converter Dust

	T. Fe	SiO_2	Al_2O_3	T. S	MgO	Na_2O	K_2O	CaO	ZnO	PbO	T.C	MiO	MnO
A Co.	29.6	8.5	3.35	1.1	1.45	1.65	0.17	22.85	0.7	0.15	4.85	-	-
B Co.	45.07	8.76	3.30	0.154	1.32	0.32	0.17	8.91	1.99	0.36	9.93	0.02	-
C Co.	32.92	6.92	2.50	1.23	5.57	0.57	0.16	13.88	0.57	0.09	2.16	-	4.44

Table 4 Electrical Resistivity of Converter Dust

	30 deg C	60 deg C	90 deg C	difficulty in collection
A Co.	6.78×10^{11} Ω-cm	6.83×10^{12} Ω-cm	1.04×10^{13} Ω-cm	normal
B Co.	5.3×10^{5} Ω-cm	9.6×10^{5} Ω-cm	5×10^{6} Ω-cm	easy
C Co.	7.31×10^{12} Ω-cm	9.11×10^{12} Ω-cm	1.07×10^{13} Ω-cm	normal

Table 5 Design and Operation Data of REP for Converter Shop

Installations		Total Gas Vol. m^3/min	Gas Vol. per Converter m^3/min	Gas Vel. m/s	Inlet Dust Loading g/Nm^3	Outlet Dust Loading g/Nm^3	Remarks
A	Design	24000	8000	1.77	0.1	0.02	LD
	Actual	13600-28600	4500-9500	1.0-2.1	0.269 (max.)	0.047	80 t/ch.x 3
B	Design	43800	14600	1.78	0.4	0.03	LD 250 t/ch.
	Actual	51000	17000	1.9	0.33	0.02	x 3
C	Design	30900	7700	0.8	0.4	0.02	LD 160 t/ch.
	Actual	42400	10600	1.1	0.35	0.02	x 3
D	Design	27000	13500	1.66	0.4	0.03	Q-BOP 230 t/
	Actual	9800-22800	4900-11400	0.6-1.4	1.09 (max.)	0.038	ch. x 2

Remarks: SHI-Type REP's.

Table 6 Design and Operation Data of REP for Electric Furnace

Installations		Total Gas Vol. m^3/min	Gas Vol. per Electric F. m^3/min	Gas Vel. m/s	Inlet Dust Loading g/Nm^3	Outlet Dust Loading g/Nm^3	Remarks
A	Design	8200	8200	1.0	0.2	0.02	100 t/ch.
	Actual	10700	10700	1.3	0.2-0.4	0.01-0.03	x 1
B	Design	4900	4900	1.0	0.3	0.03	30 t/ch.
	Actual	4600	4600	0.94	0.15-0.29	0.01-0.02	x 1
C	Design	5600	2800	1.0	0.3	0.03	18 t/ch.
	Actual	6800-9000	3400-4500	1.2-1.6	0.16-0.42	0.01-0.03	x 2
D	Design	4000	2000	1.0	0.3	0.03	8 t/ch.
	Actual	3700	1950	0.92	0.1-0.16	0.01-0.015	x 2

Remarks: SHI-Type REP's.

Table 7 Comparison of Power Consumption between REP and Bag-House (Converter Shop)

	Gas Volume (m^3/min)	Power Consumption (kw)	
		Bag-House	REP
A Co.	24000	2800	41
B Co.	43800	5100	150
C Co.	30900	3600	170
D Co.	27000	3100	90

Table 8 Comparison of Power Consumption between REP and Bag-House (Casting Floor of Blast Furnace)

	Gas Volume (m^3/min)	Power Consumption (kw)	
		Bag-House	REP
A Co.	35000	3500	240

Table 9 Comparison of Power Consumption between REP and Bag-House (Electric Furnace Shop)

	Gas Volume (m^3/min)	Power Consumption (kw)	
		Bag-House	REP
A Co.	4000	930	50
B Co.	8200	1900	100
C Co.	4900	1120	63
D Co.	2440	560	40
E Co.	5600	1290	38
F Co.	2670	620	40
G Co.	2450	560	45
H Co.	1100	1250	25
I Co.	1400	1250	35
J Co.	38000	8750	330

Table 10 Comparison of Total Energy Consumed in Ten Years in Case A Bag-House Is Replaced by REP

(30 t/ch. Electric Furnace)

	Item		Bag-House	REP
Power Consumption	High Voltage Power Supply		—	10.7kwx7200h/yx10y = 770,400 kwh
	Suction Fan		1100kwx7200h/yx10y = 79,200,000 kw	
	Accessories		10kwx7200h/yx10y = 720,000 kw	20kwx7200h/yx10y = 1,440,000 kw
	Total		79,920,000 kwh = 195.8 x 10^9 kcal	2.210,4000 kwh = 5.4 x 10^9 kcal
Production of Materials	Collector	Steel (85 t)	-	85tx11.2x10^6kcal/t= 952x10^6 kcal
		Plastics (13 t)	-	13tx13.0x10^6kcal/t = 169x10^6 kcal
	Steel for Reinforcement-of Roof (39t)		-	39tx11.2x10^6kcal/t= 437x10^6 kcal
	Total		-	1,558 x 10^6 kcal

Table 12 Number and Nominal Capacity of Electric Furnaces and Converters in Japan (Dec. 1976)

Electric Furnace		Converter	
Nominal Capacity (t)	Number	Nominal Capacity (t)	Number
5 - 18	185	40 - 90	38
20 - 35	92	100 - 180	34
40 - 60	73	200 - 270	25
70 -	28	300 -	7
Aver. Nom. Cap. 27 t	Total 378	Aver. Nom. Cap. 152 t	Total 104

Table 11 Comparison of Total Energy Consumption in Ten Years between Bag-House and REP

(160 t/ch. Converter)

	Item		Bag-House	REP
Power Consumption	High Voltage Power Supply		—	23kwx8400h/yx10y = 1.932x10^6 kw
	Suction Fan		1700kwx8400h/yx10y = 142.8x10^6 kw	—
	Accessories		20kwx8400h/yx10y = 1.63x10^6 kw	20kwx8400h/yx10y = 1.63x10^6 kw
	Total		144.48x10^6 kw = 354x10^9 kcal	3.612x10^6 kw 8.8x10^9 kcal
Production of Materials	Collector	Steel	450tx11.2x10^6kcal/t = 5,040x10^6 kcal	115tx11.2x10^6kcal/t = 1,288x10^6 kcal
		Plastics	24tx13x10^6kcal/t = 312x10^6 kcal	20tx13x10^6kcal/t = 260x10^6 kcal
	Suction Fan & Duct System (126 t)		126tx11.2x10^6kcal/t = 1,411.2x10^6 kcal	-
	Steel for Reinforcement of Roof (54 t)		-	54tx11.2x10^6kcal/t = 604.8x10^6 kcal
	Concrete (125 m^3)		125m^3x4.8x10^6kcal/m^3 = 600x10^6 kcal	-
Total			7,363.2x10^6 kcal	2,152.8x10^6 kcal

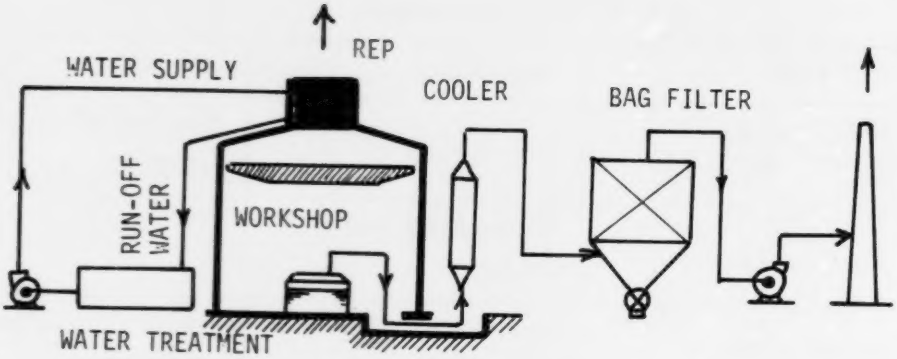

REP
WATER SUPPLY
COOLER
BAG FILTER
RUN-OFF WATER
WORKSHOP
WATER TREATMENT

Fig. 1 System of ROOF MOUNTED TYPE ESP

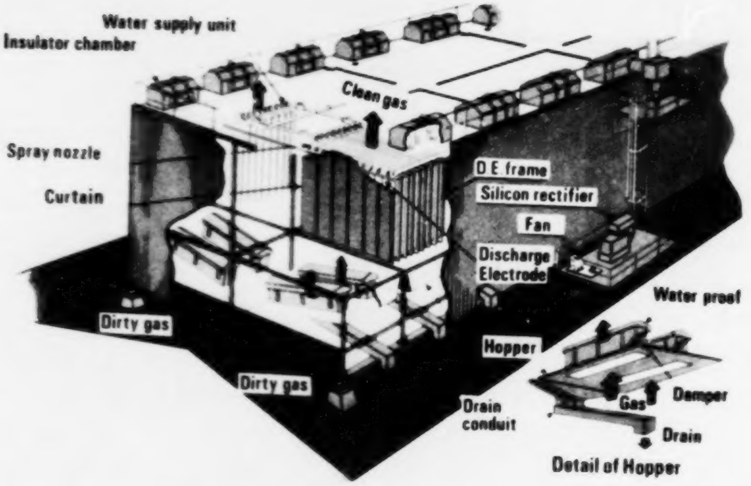

Water supply unit
Insulator chamber
Clean gas
Spray nozzle
Curtain
D.E frame
Silicon rectifier
Fan
Discharge Electrode
Water proof
Dirty gas
Hopper
Dirty gas
Drain conduit
Gas
Damper
Drain
Detail of Hopper

Fig. 2 Construction of ROOF-MOUNTED TYPE ELECTROSTATIC PRECIPITATOR (SHI-Type)

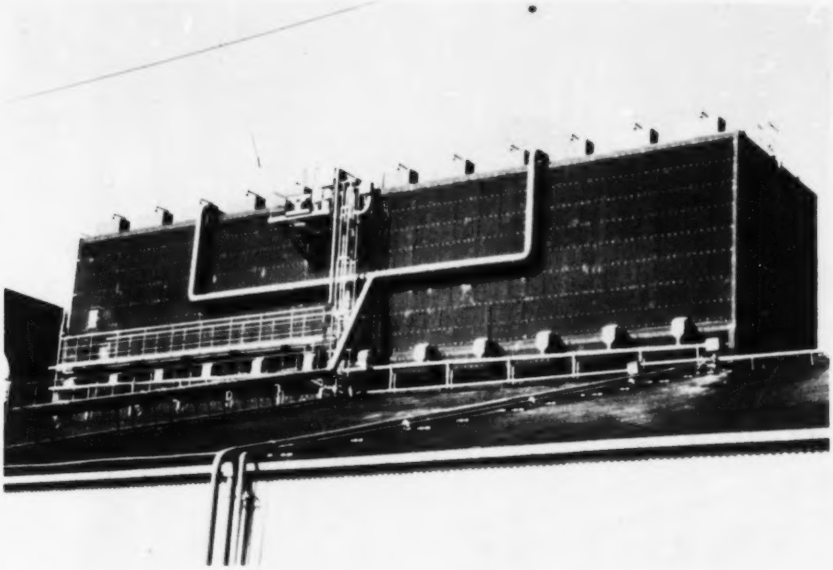
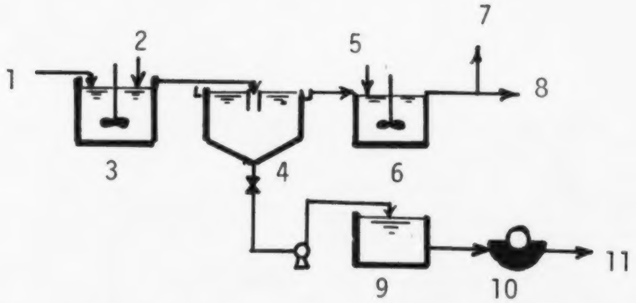


Fig. 3 ROOF-MOUNTED TYPE ESP for Converter Shop (SHI-Type)



1 waste water

2 chemical additive (pH-control)

3 stroage and neutralization tank

4 sedimentation tank

5 chemical additive

6 netralization tank

7 recycling water for spray

8 final effluent

9 sludge storage tank

10 hydroextractor

11 cake

Fig. 4 Waste Water Treatment for REP

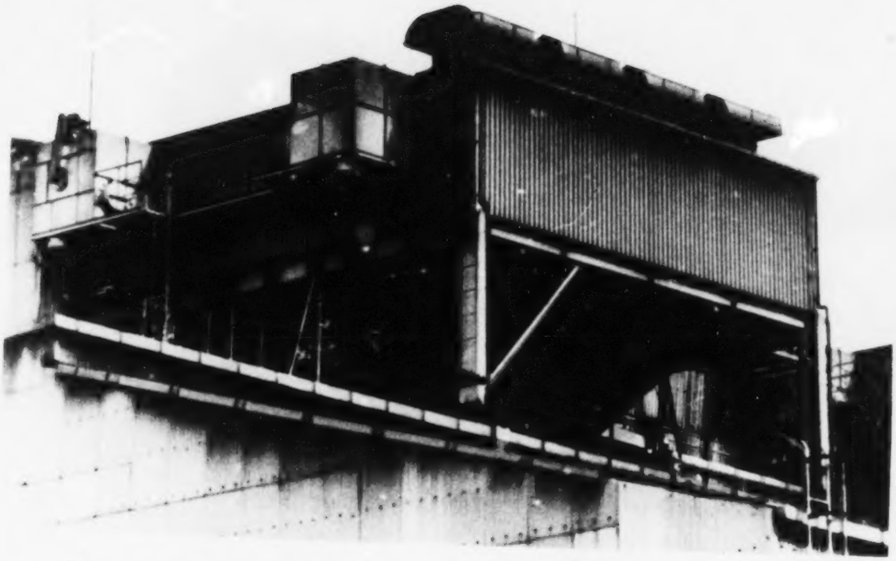


Fig. 5 ROOF-MOUNTED TYPE ESP (SMM-Type)

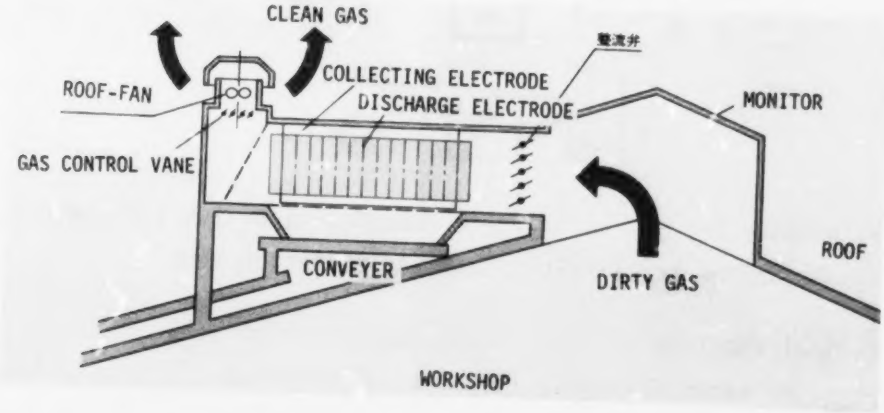

CLEAN GAS
整流弁
ROOF-FAN
COLLECTING ELECTRODE
DISCHARGE ELECTRODE
MONITOR
GAS CONTROL VANE
ROOF
CONVEYER
DIRTY GAS
WORKSHOP

Fig. 6 Construction of ROOF-MOUNTED TYPE ESP (SMM-Type)

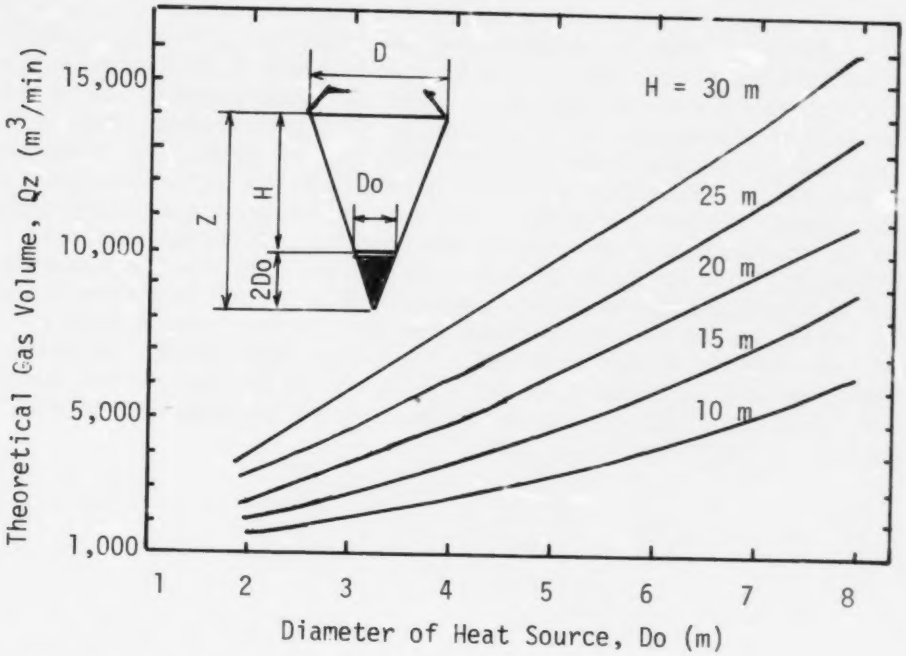


Fig. 7 Chart of Theoretical Gas Volume, Qz.

FUGITIVE HYDROCARBON EMISSIONS FROM AN IN-SITU OIL SHALE RETORT

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Oil shale has been recognized as a potentially substantial energy resource in the United States for more than a century. An emerging technology for shale oil production is in-situ processing, in which the shale bed is hydraulically or explosively fractured and retorting is carried out underground. In order to assess potential environmental impacts from in-situ processing, data were collected on fugitive emissions from a pilot-scale retort producing 30 barrels of crude shale oil daily. Fugitive gas seepage through the retort surface and from around instrumentation well casings was measured using a specially designed sampling system in conjunction with gas chromatographic and Orsat analysis. Total hydrocarbons, C_1 through C_6 hydrocarbon fractions, and carbon monoxide were quantified in the fugitive emission samples. Normalized fugitive hydrocarbon emission rates due to seepage through the overburden ranged from 0.2 to 18 $g/m^2/hr$, with an average of 5.5 $g/m^2/hr$. The total hydrocarbon emission rate due to ground seepage was calculated to be 5.7 kg/hr, using the retort surface area of 1,043 m^2; fugitive hydrocarbon emissions due to leakage around well casings amcunted to an additional 0.3 kg/hr.

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Potsdam, New York.

FUGITIVE HYDROCARBON EMISSIONS FROM AN IN-SITU OIL SHALE RETORT

Introduction

Oil shale has been recognized as a potentially substantial energy resource in the United States for more than 100 years. Rapidly escalating oil prices have provided new incentive for shale oil recovery from deposits in Colorado, Utah, and Wyoming. At least four U.S. firms (Colony Development Operation, Paraho Development Corporation, Superior Oil Company, and Union Oil Company) have developed surface retorting processes, in which oil shale is mined and crushed prior to thermal processing in above-ground facilities. The costs associated with mining and handling voluminous quantities of raw shale and the environmental impact of spent shale disposal may limit commercial application of this technology.[1] Therefore, a good deal of research is currently being directed toward the development of in-situ or modified in-situ retorting processes. This technology, in which the shale bed is hydraulically or explosively fractured and retorting is carried out underground, may offer a cost-effective solution to the shale handling and disposal problems associated with surface retorting.[1] In-situ or modified in-situ processes are now being developed by Equity Oil Company, Geokinetics, Inc., Rio Blanco Oil Shale Company, and Occidental Oil Shale, Inc.

Since in-situ oil shale retorting is an emerging energy technology, its potential environmental impacts are largely unknown. Under Contract No. 68-03-2550 for the U.S. Environmental Protection Agency (EPA), a field sampling program was conducted to identify and quantify emissions and effluents resulting from horizontal in-situ oil shale retorting. The technical description and results presented herein are concerned only with the measurement of fugitive emissions from a pilot-scale retort, located on the Kamp Kerogen site in Uintah County, Utah, and operated by Geokinetics, Inc. The shale bed was rubblized in May 1978 and ignited in April 1979; field sampling was conducted from July 16 to July 26, during which time the crude shale oil production rate was approximately 30 barrels per day.

The Geokinetics horizontal in-situ retorting process begins with the drilling of blast holes from the surface, through a maximum of 46 m of overburden, and into the oil shale bed.[2] The holes are then loaded with explosives, which are fired to yield a rubblized mass of oil shale with increased permeability. During fragmentation, the surface undergoes noticeable uplift. A slope is created below the oil shale bed, allowing shale oil to drain to a sump for recovery by production wells, as shown in Figure 1.

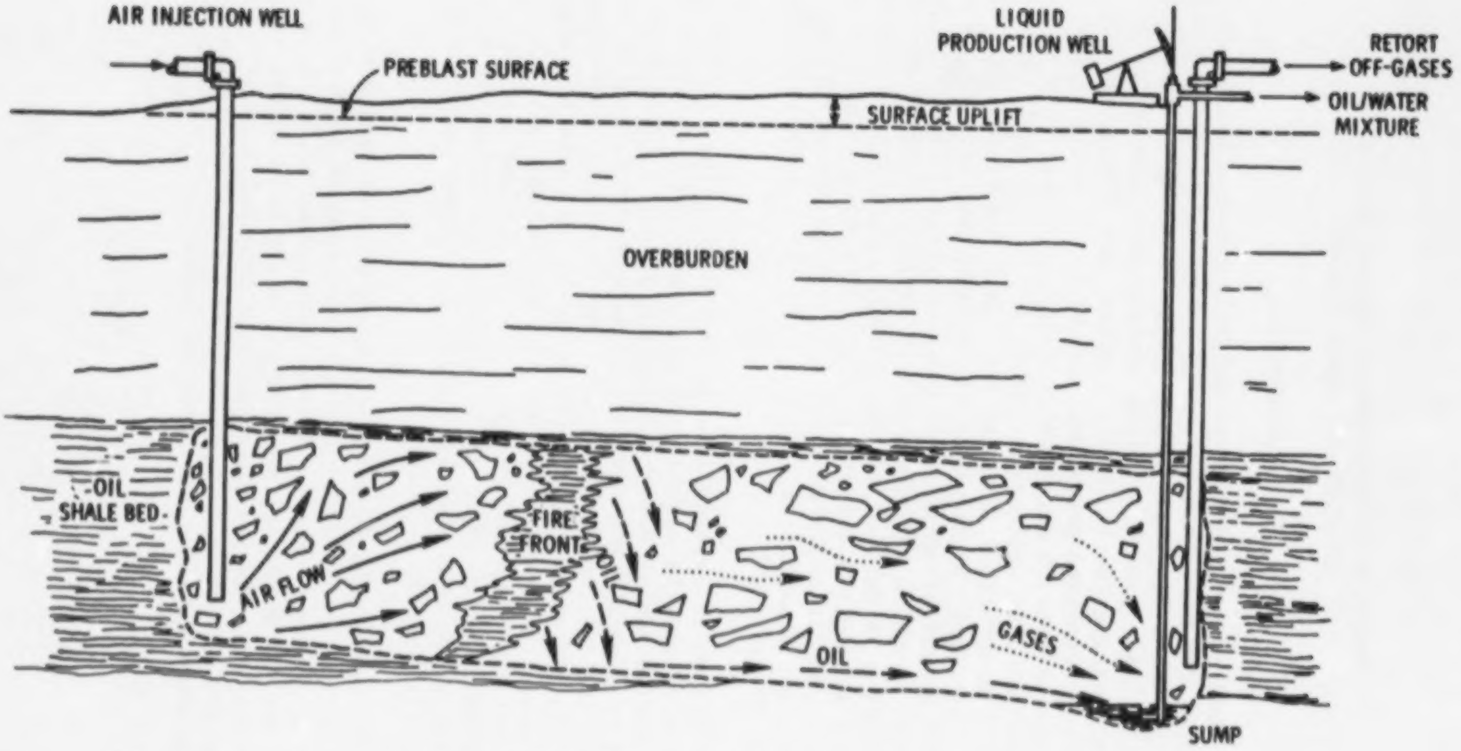
AIR INJECTION WELL
PREBLAST SURFACE
LIQUID PRODUCTION WELL
RETORT OFF-GASES
OIL/WATER MIXTURE
SURFACE UPLIFT
OVERBURDEN
OIL SHALE BED
AIR FLOW
FIRE FRONT
OIL
OIL
GASES
SUMP

Figure 1. Sectional view of Geokinetics horizontal *in-situ* oil shale retort.

Experimental Methods

The uplift of the retort overburden, due to shale deposit fragmentation, causes ground cracks of various sizes. Plant personnel routinely seal major cracks by filling with mud and tamping before retorting begins, but escape of gases from the burning retort is not entirely eliminated. However, because it was Geokinetics' understanding that the purpose of this fugitive emissions study was characterization, not quantification, only those leaks that presented an obvious health hazard were sealed during the sampling period. Additional sources of fugitive emissions are created by drilling and casing instrumentation wells into the oil shale bed. It has been estimated that one-third to one-half of the total volume of gas injected into the in-situ retort is not recovered at the outlet wells.[3] A 30 kw (40 hp) vacuum blower, capable of reducing, if not altogether preventing, such gas seepage, was not in operation during the sampling period.

In order to obtain representative data, test locations for fugitive gas sampling were randomly selected, with the constraint that an approximately equal number of sites be placed in each of four quadrants of the surface area of the retort. Locations for sampling ground seepage were selected by using a random number table corresponding to consecutively numbered squares on a grid superimposed over a scale diagram of the retort. Twenty-seven of these potential fugitive emission sources were tested, non-simultaneously, along with six thermocouple wells and one of two shale oil production wells.

The sample collection method used in this effort was developed by combining the applicable features of techniques previously used extensively in the measurement of fugitive emissions from sources as diverse as vegetation and petrochemical processing equipment.[4,5] Prior to sampling, selected test locations were enclosed using an aluminum box, 0.61 m square, having an open top and bottom. The aluminum box was driven into the soil and anchored at all four corners with metal rods; moist soil was used outside the bottom of the sampling box to provide a seal to the retort surface. The top of the box was covered with flexible plastic, attached to the sides by duct tape.

Figure 2 is a schematic diagram of the fugitive emission sampling system used at the Geokinetics' oil shale retort. The sample box outlet was connected, via a three-way valve, to a 500-mL glass syringe and to a vacuum pump. For approximately five minutes prior to sample collection, the pump was used to evacuate the sample box, after which the pump was disconnected and replaced with a Teflon sample bag. The three-way valve was then adjusted so as to seal the sample box off from both the syringe and the sample bag. The aluminum box was next filled with "zero-grade" air from a pressurized cylinder at a measured rate of 10 liters per minute, causing the plastic cover sheet to rise. When the box was partially inflated, a sample was obtained by using the syringe to withdraw a portion of the gas containing fugitive emissions and, after turning the three-way valve, to inject this into a Teflon bag. Field "blanks", consisting of samples of zero-grade air which were

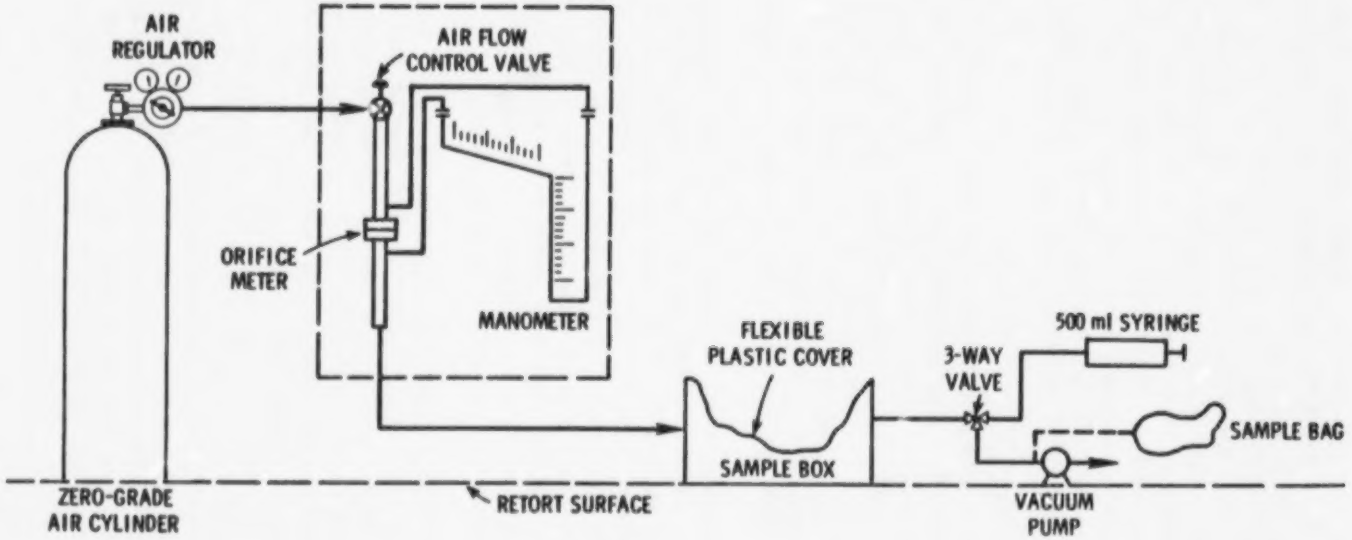
AIR REGULATOR
AIR FLOW CONTROL VALVE
ORIFICE METER
MANOMETER
FLEXIBLE PLASTIC COVER
3-WAY VALVE
500 ml SYRINGE
SAMPLE BAG
SAMPLE BOX
ZERO-GRADE AIR CYLINDER
RETORT SURFACE
VACUUM PUMP

Figure 2. Fugitive emission sampling system.

passed through the flow control valves, the orifice meter, and all connecting lines, but not the sample box, were also collected using the glass syringe and Teflon bags.

Samples contained in the Teflon bags were analyzed on-site for total hydrocarbons and C_1 through C_6 hydrocarbon fractions using a portable gas chromatograph with a flame ionization detector. Selected fugitive emission samples were also tested for carbon dioxide (CO_2), carbon monoxide (CO), and oxygen (O_2) by Orsat analysis.

Results

The rates of fugitive gas seepage from the retort surface and from around well casings were determined using the following equation, which is based on the ideal gas law (and which includes a numerical constant accounting for conversion of mm Hg to atmospheres, liters to cm^3, and minutes to hours):

$$E = 7.895 \times 10^{-5}\ M\ P_s\ G(C_s - C_b)/RT_s \qquad (1)$$

where E = fugitive emission rate, g/hr
M = molecular weight of emitted material, g/g-mole
P_s = atmospheric pressure during sampling, mm Hg
G = cylinder gas flow rate, liters/min
C_s = concentration in sample bag, ppm
C_b = concentration in field blank, ppm
R = ideal gas constant = 82.1 cm^3·atm/g-mole·°K
T_s = ambient temperature during sampling, °K

The calculated hydrocarbon emission rates for tested sources are given in Table I. Emission rates for ground seepage sources were normalized by dividing by the cross-sectional area of the sample box, equal to 0.37 m^2.

The average hydrocarbon emission rate for ground seepage was 5.5 g/m^2/hr, with a range of 0.2 to 18 g/m^2/hr. In Figure 3, the distribution of measured hydrocarbon emission rates over the surface of the retort is shown. The total fugitive hydrocarbon emission rate of 6.0 kg/hr was calculated by adding the product of the average ground seepage rate (5.5 g/m^2/hr) and the retort surface area (1,043 m^2) to product of the average emission rate from wells (5.3 g/hr) and the total number of wells (46).

Additional analyses were conducted to determine the general composition of hydrocarbons in the fugitive emission samples. Table II gives the concentrations of C_1 through C_6 hydrocarbon fractions for selected bag samples. Orsat analyses of selected samples are given in Table III.

Table I. Fugitive hydrocarbon emission rates.[a]

Sample type and run number	Hydrocarbon emission rate, g/m²/hr	Sample type and run number	Hydrocarbon emission rate, g/m²/hr
Ground seepage:			
G-1	2.9	Ground seepage (continued):	
G-2	0.4		
G-3	14	G-22	0.5
G-4	11	G-23	3.3
G-5	15	G-24	7.0
G-6	5.7	G-25	2.9
G-7	0.3	G-26	8.0
G-8	0.7[b]	G-27	2.4
G-9	3.4		
G-10	6.8	Liquid production well:	
G-11	18	P-1	7.8[b]
G-12	10		
G-13	5.6		
G-14	7.0	Thermocouple wells:	
G-15	1.6	T-1	–[c]
G-16	0.9	T-2	4.8[b]
G-17	8.5	T-3	3.7[b]
G-18	4.9	T-4	6.9[b]
G-19	2.4	T-5	5.4[b]
G-20	0.3	T-6	3.1[b]
G-21	0.2		

[a] Emission rates per unit area determined by dividing hourly rate by sample box area of 0.37 m^2.

[b] Emission rate given in g/hr (sample box not used).

[c] Thermocouple well sample No. T-1 was not analyzed.

Discussion

The total fugitive hydrocarbon emission rate of 6.0 kg/hr is significant when compared to the 17 to 19 kg/hr of hydrocarbon vapors contained in the retort's off-gas outlet wells, the latter quantities having been determined in the overall study of Geokinetics' technology.[6] In order to make a preliminary assessment of the impact of fugitive hydrocarbon emissions on ambient air quality in the vicinity of retort, dispersion modeling, according to the method of Turner,[7] was used to calculate ground-level hydrocarbon concentrations. The following assumptions were made: 1) the emissions originate from

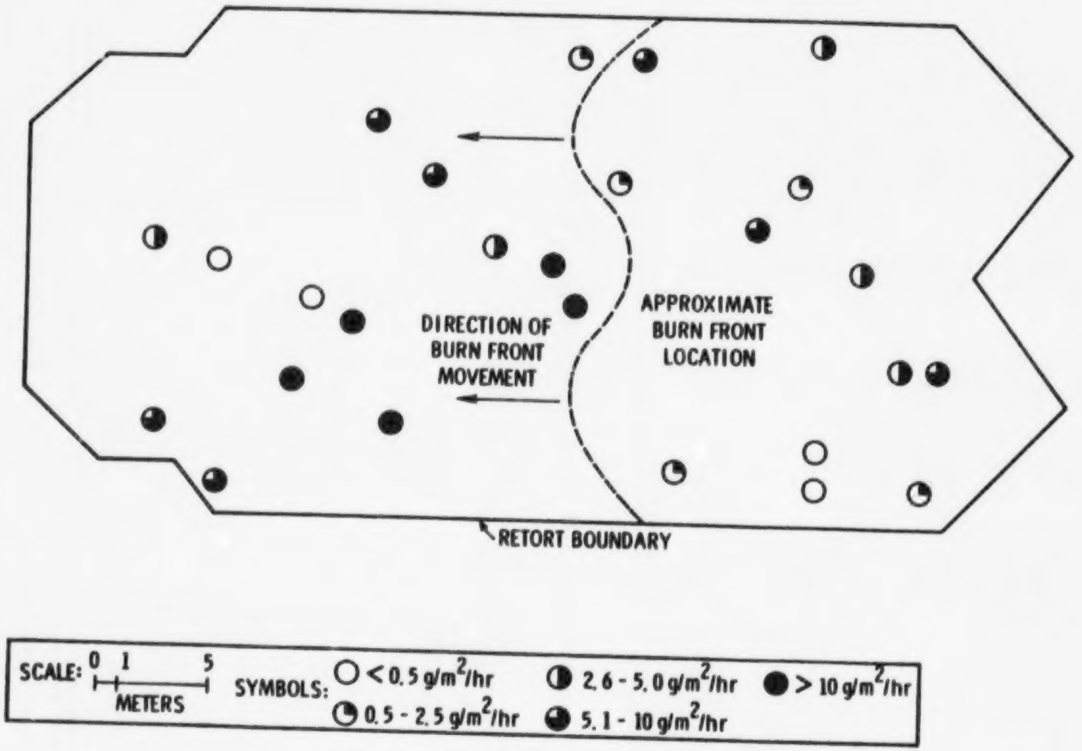
APPROXIMATE BURN FRONT LOCATION
DIRECTION OF BURN FRONT MOVEMENT
RETORT BOUNDARY
SCALE: 0 1 5 METERS
SYMBOLS: ○ < 0.5 g/m²/hr
◔ 0.5 - 2.5 g/m²/hr
◑ 2.6 - 5.0 g/m²/hr
◕ 5.1 - 10 g/m²/hr
● > 10 g/m²/hr

Figure 3. Pictorial representation of magnitude of fugitive hydrocarbon emissions due to seepage through retort surface.

Table II. Concentrations of C_1-C_6 hydrocarbon fractions in selected fugitive emission samples.

Sample type and run number	Concentration, ppmv					
	C_1	C_2	C_3	C_4	C_5	C_6
Ground seepage:						
G-4	1,700	360	100	20	50	5
G-11	2,900	650	240	160	90	8
G-14	1,200	330	100	80	20	3
G-17	1,700	480	190	110	50	7
G-24	1,300	360	120	110	50	4
Liquid production well:						
P-1	740	240	90	40	20	1
Thermocouple well:						
T-2	810	200	60	50	20	3

Table III. Orsat analysis of selected fugitive emission samples.

Sample type and run number	Concentration (dry basis), percent by volume			Carbon monoxide emission rate, $g/m^2/hr$
	Carbon dioxide (CO_2)	Oxygen (O_2)	Carbon monoxide (CO)	
Ground seepage:				
G-9[a]	0.2	10.6	1.0	21
G-13[b]	5.0	7.0	1.1	23
G-18[a]	4.0	7.2	0.8	17
G-24[a]	8.0	5.8	0	0
Thermocouple well:				
T-4[b]	3.6	7.4	1.8	40[c]

[a] Concentrations are averages of duplicate analyses of sample.

[b] Concentrations are averages of triplicate analyses of sample.

[c] Emission rate given in g/hr (sample box not used).

a "point source," not strictly correct in this case but proven by calculations to be adequate for order-of-magnitude estimation; 2) the atmospheric stability is represented by Class C; and 3) the averaging time is three hours, that for the ambient air quality guideline for hydrocarbons. In addition, a wind speed of 3 m/s, equivalent to the national average but corrected from a height of 7 m to 1 m, was utilized. The calculated results are meant to approximate concentrations, not to replace ambient air monitoring, because the accuracy of Turner's method is limited to within a factor of two or three due to empirical determination of dispersion constants.

Table IV is a matrix of downwind ground-level hydrocarbon concentrations calculated using the total fugitive emission rate of 1.7 grams per second. Assuming the "point source" of fugitive emissions is located at the mid-point of the downwind boundary of the retort, Table IV indicates that, within a limited area nearby, the hydrocarbon concentration exceeds the ambient air quality guideline of 160 µg/m^3. During the three-hour averaging time, this phenomenon occurs only within approximately 20 meters of the "plume" centerline and up to approximately 300 meters downwind of the retort. Extrapolating from the pilot-scale retort to a commercial facility operated at a much greater shale oil production rate, the mass flow rate of fugitive hydrocarbon emissions is expected to be greater, and the ambient air quality effects would thus extend to a larger area than that suggested by Table IV.

Table IV. Downwind ground-level concentrations due to fugitive hydrocarbon emissions from Geokinetics retort.

x,[b] meters	Concentration[a], µg/m^3					
	y,[c] meters					
	0	10	20	50	100	200
10	69,000	-[d]	-	-	-	-
20	20,000	110	-	-	-	-
50	3,700	1,400	70	-	-	-
100	1,100	800	350	1	-	-
200	300	280	220	40	-	-
500	60	60	50	40	10	-
1,000	20	20	20	10	10	3
2,000	5	5	5	4	4	3

[a] Calculated using the total fugitive hydrocarbon emission rate of 1.7 g/s.

[b] Downwind distance along the "plume" centerline.

[c] Horizontal distance from the "plume" centerline.

[d] Dash indicates calculated concentration was less than 1 µg/m^3.

Acknowledgements

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7. Turner, D. B. Workbook of Atmospheric Dispersion Estimates. Public Health Service Publication No. 999-AP-26, U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio, May 1970. 84 pp.

A WIND TUNNEL STUDY OF FUGITIVE DUST FROM TACONITE STORAGE PILES

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ABSTRACT

A comparative wind tunnel study of the fugitive emissions from a taconite pellet test surface conducted at Purdue University indicates that one of the three commercially available dust suppressing agents tested at a dilution ratio of 1 to 1000 was 33% more effective than the least effective agent. Water only was also found to be as effective as the dust suppressing agents. However, water and dust suppressing agents resulted in 3 times higher particulate emissions than that of a dry pile. Both dry and wet transient tests elucidated the nature of the particulate release. For the wetted pellets, subsurface drying appears to "mobilize" interstitial and surface pellet material which resulted in a higher release rate of particulate matter in time as compared to a dry pellet.

INTRODUCTION

This report summarizes the results of a Purdue University study which investigated the effectiveness of various binding agents to control fugitive dust emissions from taconite surfaces. The three agents tested were composed of hi-molecular weight polymers and synthetic resins. They were all diluted 1:1000 with Indiana tap water. At the outset, it should be understood that this study is not a modeling study of a full size taconite storage pile. Rather, this study is a purely comparative study with the objective of determining which of three chemical dust suppressing agents and also water do the best job of reducing fugitive particulate emissions from taconite pellet surfaces. The study is in reality a comparative parametric study utilizing a large wind tunnel and other closely controlled procedures. All taconite preparation procedures and wind tunnel velocity were closely controlled in order to discern the downwind particulate concentrations subsequent to application of the various chemical dust suppressants.

WIND TUNNEL DESCRIPTION

The subsonic wind tunnel at the Purdue University, Aerospace Sciences Laboratory is shown in schematic detail in Figure 1. The tunnel is a conventional one with a 10-1/2 to 1 contraction ratio and is powered with a 400 H. P. electric motor. Speed control is obtained by means of a rheostat-controlled electric clutch permitting a tunnel speed range from 10 mph to 300 mph in the high-speed, closed test section.

The present test program was conducted in the large open-throat test section at the end of the 1st diffuser by means of a specifically designed and constructed assembly described in Figures 2 and 3 and shown photographically in Figure 4. This provided a flow at a nominal 1/2 of the high-speed section so speeds could be varied and controlled from approximately 5 mph to 150 mph as needed.

The tests were conducted at a fixed velocity profile in the open-throat section. The speed was monitored by means of a pitot-static tube mounted upstream of the test surface, see Figures 2, 3 and 4.

Figure 5 contains the vertical profiles of mean wind velocity and turbulence intensity. Note that over the pile height the wind velocity varied from 40 mph at the top to 20 mph near the base. Turbulence intensity varied from 2% at the top of the pile to 5.5% near the base. These levels of velocity and turbulence intensities are typical of those expected in relatively flat terrain such as would be expected from off-shore breezes which do exist near the full scale taconite piles.

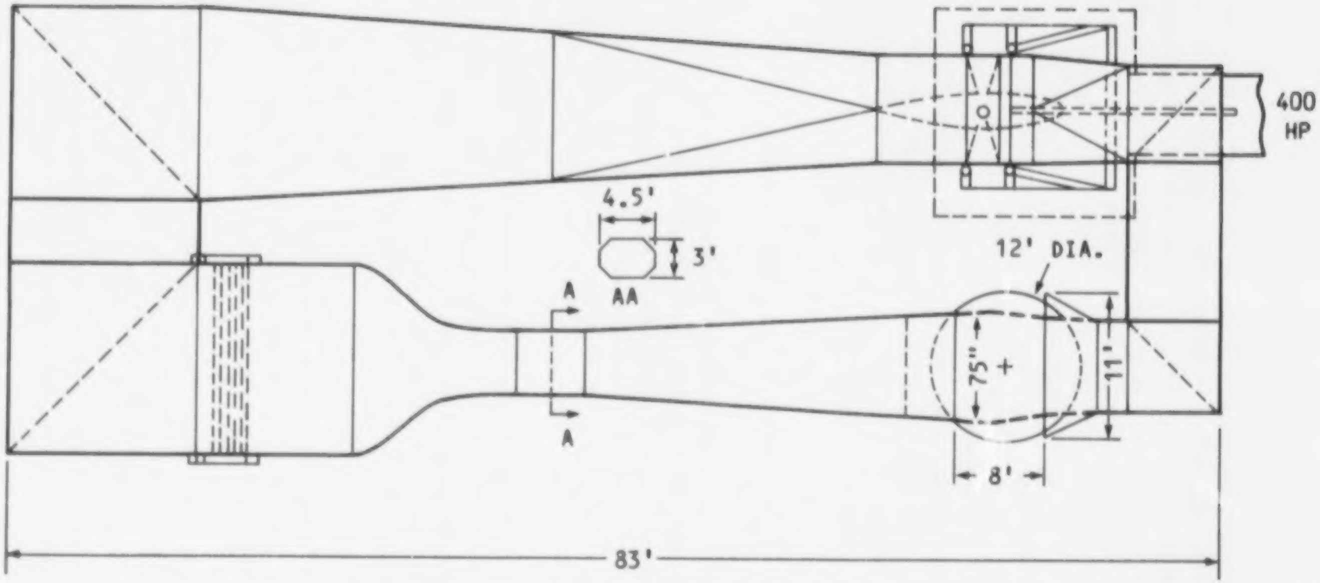

400
HP
4.5'
3'
AA
A
A
12' DIA.
75"
11'
8'
83'

FIGURE 1. LAYOUT AND ELEVATION OF THE AEROSPACE SCIENCES LABORATORY SUBSONIC WIND TUNNEL TOP VIEW.

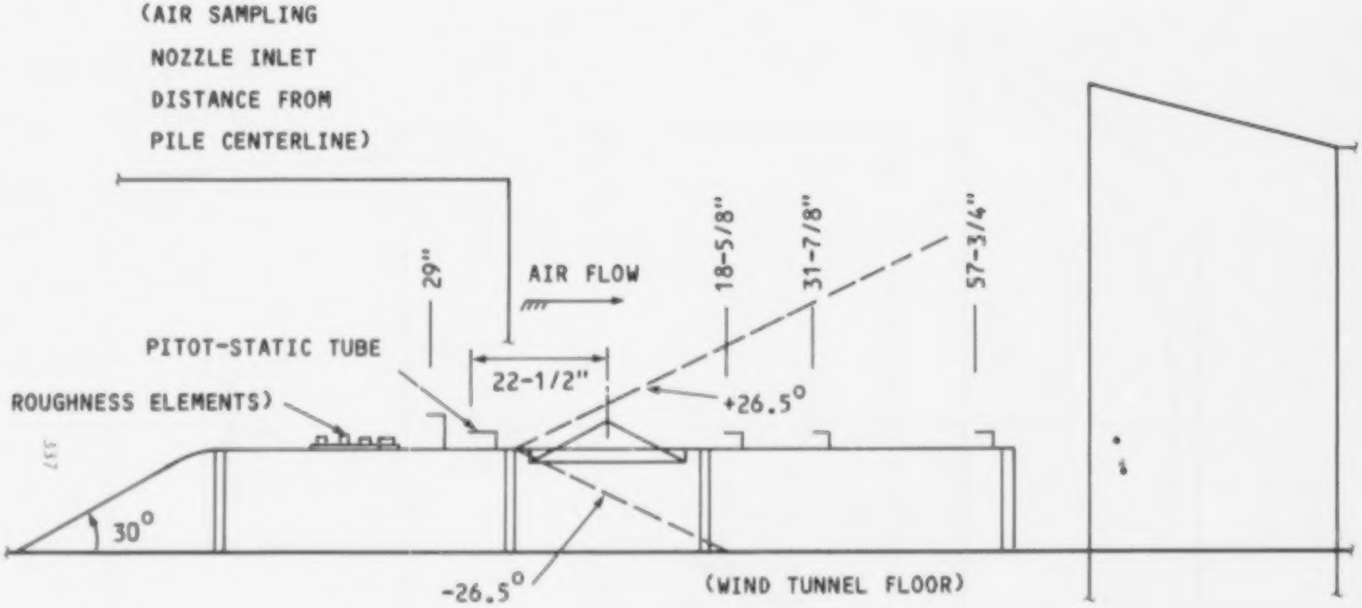

(AIR SAMPLING
NOZZLE INLET
DISTANCE FROM
PILE CENTERLINE)
29"
AIR FLOW
18-5/8"
31-7/8"
57-3/4"
PITOT-STATIC TUBE
22-1/2"
ROUGHNESS ELEMENTS)
+26.5°
30°
-26.5°
(WIND TUNNEL FLOOR)

Figure 2. Schematic Cross Section of Test Assembly.

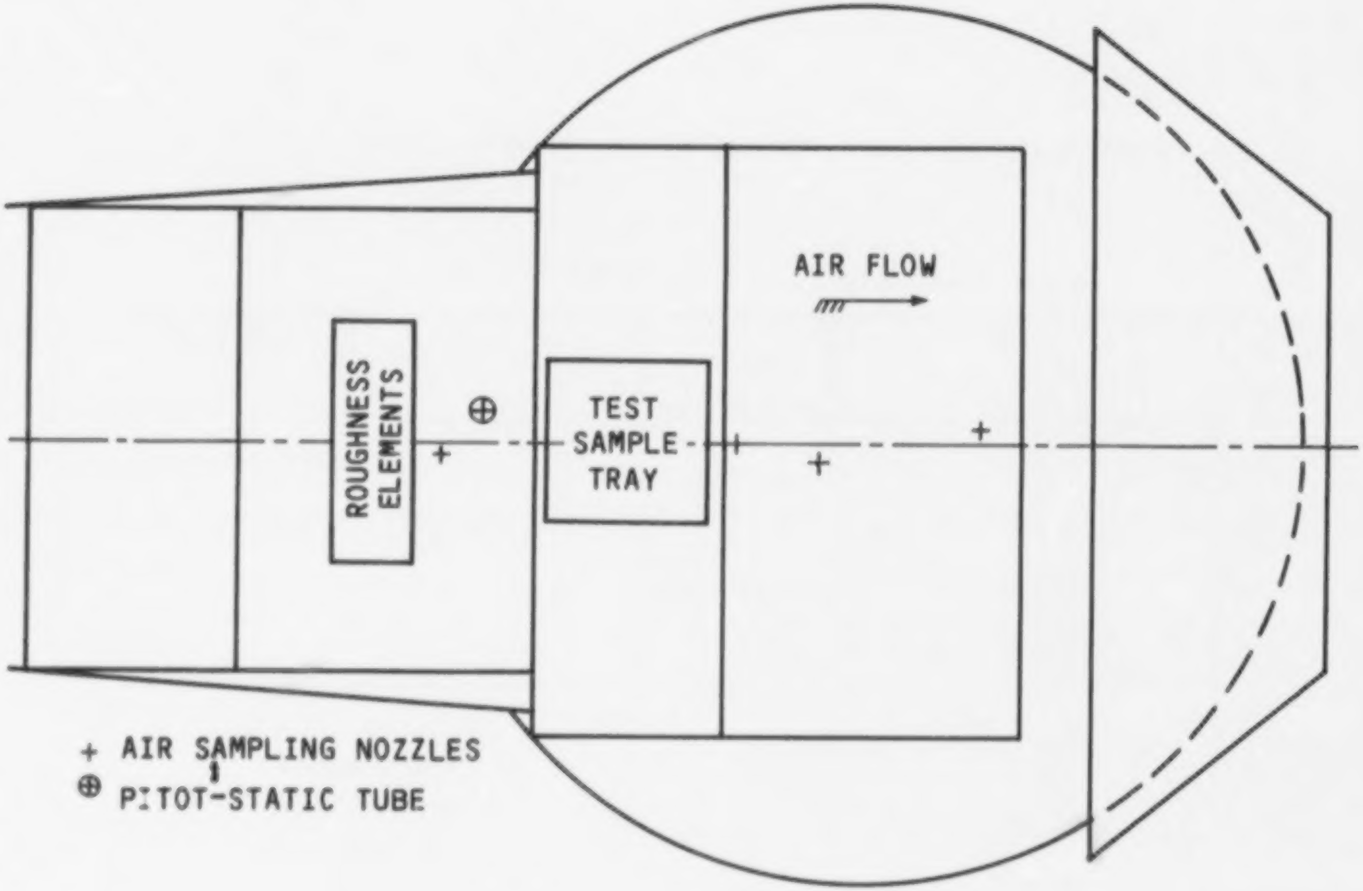
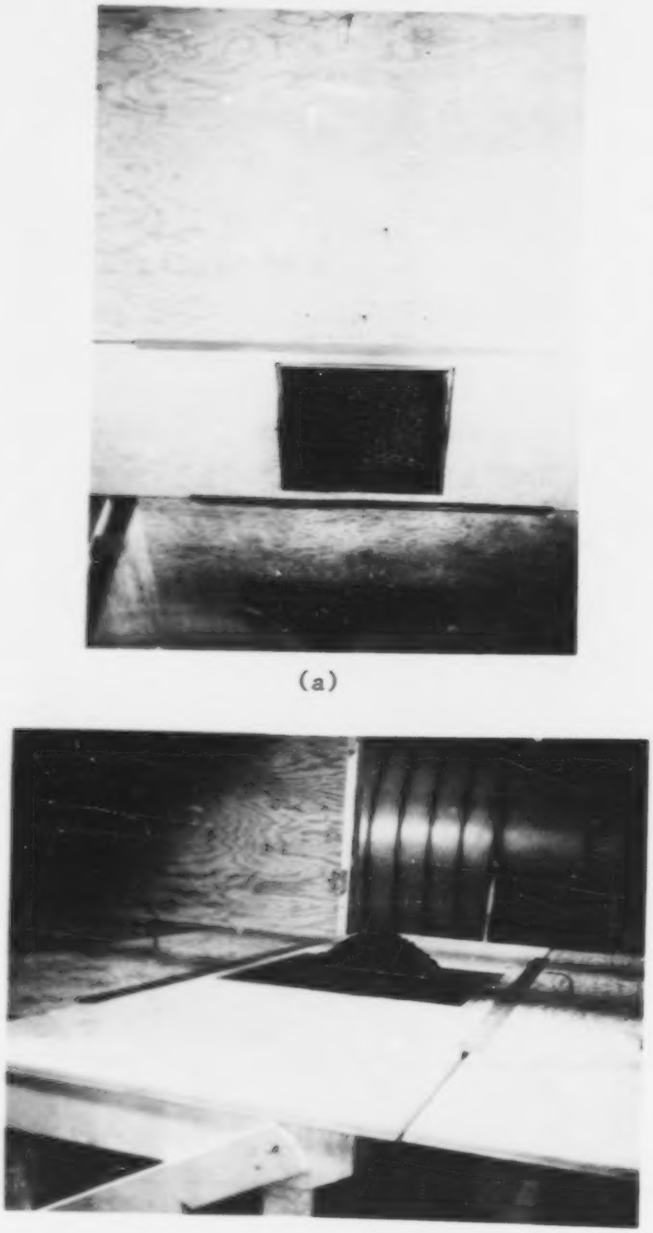

AIR FLOW
TEST SAMPLE TRAY
ROUGHNESS ELEMENTS
+ AIR SAMPLING NOZZLES
⊕ PITOT-STATIC TUBE

Figure 3. Schematic Plan View of Test Assembly in Wind Tunnel.



(a)

(b)

Figure 4. (a) Looking Upwind at Taconite Test Surface from Rear Sampling Nozzle
(b) Side [redacted] Taconite Test Surface with Flow Left to Right

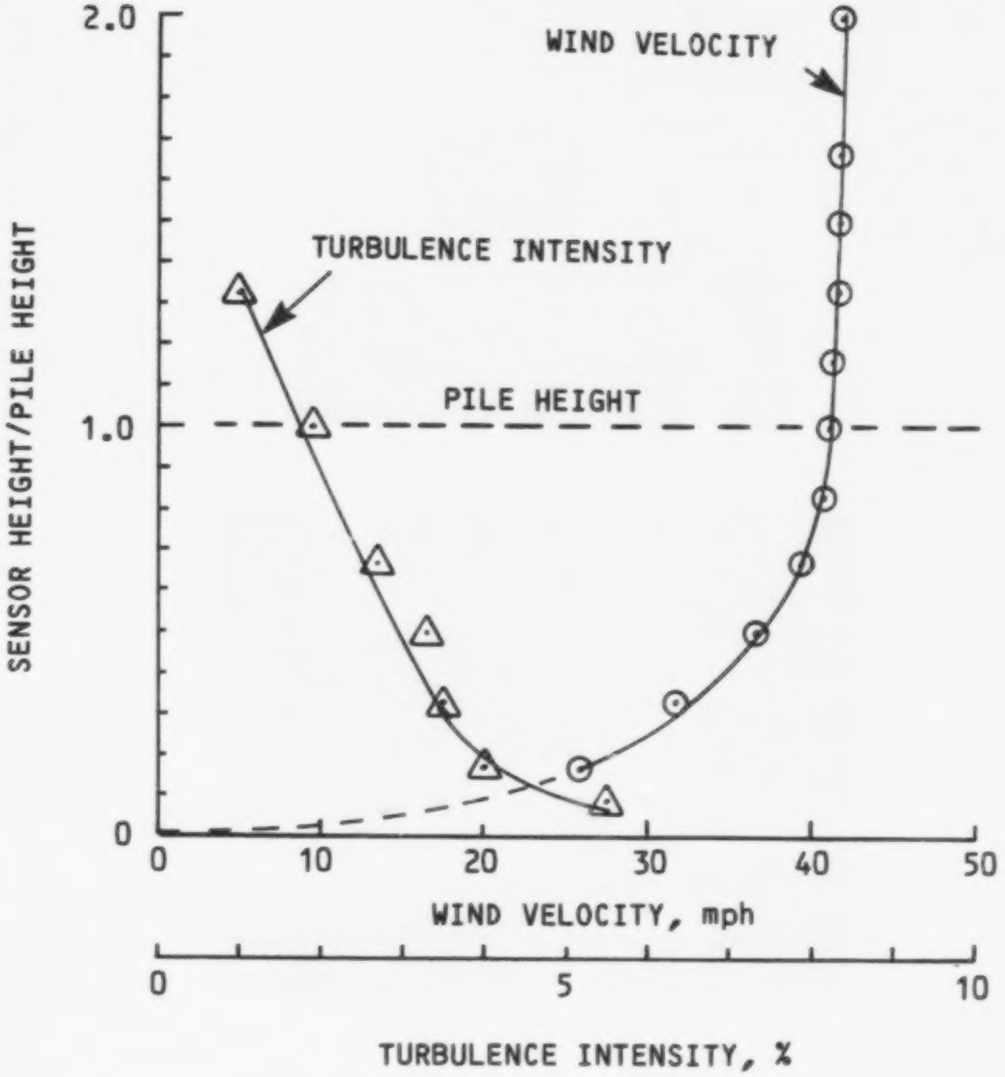


Figure 5. Vertical tunnel profiles of wind velocity and turbulence intensity at center of tunnel.

TEST ASSEMBLY

In order to facilitate testing for taconite fugitive dust, an assembly for into the wind tunnel was designed and constructed. Figures 2 and 3 are schematics of the assembly installed in the large, low-speed, open test section of the wind tunnel.

The assembly was constructed of plywood, masonite, and construction lumber. The 30° rise, see Figure 2, was constructed from untempered masonite fastened to 5 plywood ribs. This provided a stiff (non pulsing) surface with a smoothly curved transition to the horizontal surface. The horizontal surfaces were constructed with sufficient strength and stiffness to permit 2 men walking on them.

The two dashed lines label plus and minus 26.5° in Figure 2 show the hinged panels in the two positions for flat-tray attitudes of plus and minus 26.5°. The back panel lays along the tunnel floor for the minus 26.5° position.

Both Figures 2 and 3 show the assembly to scale in the horizontal position with roughness elements, instruments, and test pile location.

Figure 4a is a top view looking upstream from the last air sampling nozzle. Figure 4b is a side view of the conical test surface. Flow is left to right.

TEST PROCEDURES

Taconite Test Surface

The basic approach in this study was to present a taconite test surface to a constant velocity air stream while measuring upstream and downstream particulate concentrations. Initially it was proposed that the test surface be composed of a planar array of taconite pellets that could be presented at three angles to the tunnel wind flow. The planar surface when presented at a +26.5° angle to the wind would represent a section of the upwind face of a storage pile. When presented at a -26.5° angle to the wind the planar surface would represent the downwind face of the pile. At 0° angle the surface would represent top and edges of the storage pile. Preliminary wind tunnel tests indicated that the angle of incidence made little difference in the downwind particulate concentrations. All subsequent tests were therefore made in a horizontal mode (0° angle to the wind). In addition, the absolute downwind particulate concentration level was lower than desired for minimization of errors in the gravimetric analysis. Therefore the test surface was changed from planar to conical.

The test surface was made from taconite pellets supplied from the Michigan Upper Peninsula. A size distribution was determined for the pellets upon arrival at Purdue. It was found that virtually no sizes less than 1/4" were present in the received pellets. From previous taconite pellet size distributions it was known that copious fine dust does occur. Therefore sufficient taconite was pulverized in the soils laboratory at Purdue so that 2.5% by weight less than 149 micron dust could be added to the received pellets. A two step procedure was utilized to form the fine dust. The pellets were first placed in a ball mill for approximately one hour, then through a pulverizer. The ball mill was a "Los Angeles Type Abrasion Machine" manufactured by F. M. Welsh Engineering Service of Greenville, Ohio and the type UA pulverizer was manufactured by F. W. Braun Co., of Los Angeles, California. Table 1 below shows the resulting size distribution.

Table 1 Taconite Pellet Size Distribution

Particle Size (S)	% by Weight
3/4" < S	0.670 (as received)
1/2" < S < 3/4"	34.440 " "
3/8" < S < 1/2"	61.400 " "
1/4" < S < 3/8"	0.960 " "
(Added to the pellets in the laboratory)	
590μ < S < 1/4"	0.008
296μ < S < 590μ	0.024
149μ < S < 296μ	0.493
75μ < S < 149μ	0.261
S < 75μ	1.750

Test Surface Preparation Procedure

The size distribution in Table 1 was followed in the making of all conical test surfaces. Following is the exact procedure utilized:

1) Place 2' x 2' x 2" deep wood test tray on 800 lb. capacity Toledo® scale (31-1821-FD). Adjust scale to zero weight.
2) Use Fairbanks-Morse beam balance scale (0-250 lbs., Model 505) to weigh individual size fractions based on 100 lbs. and pour onto test tray. After weighing incremental fractions of 100 lb. on smaller beam scale, check larger Toledo scale weight to ensure a sample weight of 100 lbs. has been achieved. However, do not yet disperse less than 149 micron dust on tray.
3) The pellets were then evenly spread over a specially built wooden trough 18" wide x 10' long x 1.75" deep. The horizontal trough was supported 11-1/2" above the floor. The purpose of the trough was to present each pellet for evenly distributing the less than 149 micron dust as well as for spraying of suppressing agent.
4) Sieve the less than 149 micron size fraction of particles evenly over the pellets in the trough.
5) Using a Binks® Model 370 external mix spray gun at an inlet delivery pressure of 40 psig, evenly spray the pellets in the trough with 500 ml of the selected dust suppressing agent.
6) Using a square wooden stick 1" x 1" in cross-section and 12" long, a furrow was ploughed through the pellets along the trough centerline returning back along the trough between the outer wall and trough

centerline on each side.

7) The pellets are once again spread evenly over the trough. This procedure exposes dry sides of pellets for more thorough wetting.
8) Proceed to spray another 500 ml of dust suppressing agent on the now turned over pellets.
9) Using a 500 ml, polyethylene sealable bottle collect a sample of pellets for moisture determination.
10) Using 8" wide x 10" long metal sheets (0.040" thick) scoop the pellets and carefully pour them into the center of the test tray. In this way, the pellets, evenly dispersed with less than 149 micron particles and wetted seek their 26.5° angle of repose in the tray forming a conical test surface.
11) Any fine particulate remaining in the trough is brushed into a sieve and evenly spread over the conical test surface.
12) The conical taconite pellet test surface was then positioned in the wind tunnel. The elapsed time between wetting and test startup was kept consistently at 10 minutes (conical piling to test startup was only 2 min.).

Particulate Sampling Procedures

In order to quantify the differences between the three chemical dust suppressing agents, A, B, C and water as well as dry test surfaces of taconite, isokinetic particulate samples were taken. During each test, except the transient tests, four simultaneous isokinetic samples were extracted using stainless steel 1/4" inside diameter nozzles leading to 47 mm diameter filter holders. Gelman type AE glass fiber filters were used for all tests. All filters were handled and analyzed using standard gravimetric laboratory procedures.

One sampling nozzle was located upstream of the conical taconite test surface centerline, refer to Figure 2 and 3. The upstream sample served as a "blank" to correct the downstream samples for particulate concentration. All samples were withdrawn isokinetically at 1.2 ft. ^{3}/min. Adjacent to the upstream sampling nozzle a standard pitot-static tube was located for measuring tunnel speed and maintaining isokinetic conditions. The pitot tube as well as all sampling nozzles were offset (staggered) from the tunnel and conical test surface centerline so none was in the direct downstream wake flow of the nearest upstream nozzle.

Air Flow Instrumentation

The air samples were taken using 3 EPA Method 5 type control cases (Joy Manufacturing Co.) and one diaphram pump and a rotameter. The method 5 type control cases are equipped with a leak-free vacuum pump, dry gas meter, flow control valves and an orifice rate meter. The orifice meter was used to set up the isokinetic sampling rate. Each control case was previously calibrated against wet test meters in the School of Civil Engineering's Air Pollution Measurements Laboratory. The fourth pump and rotameter were also calibrated prior to use. All air volumes measured were corrected to standard conditions.

Specific Test Procedures - 60 min. Samples

With the wind tunnel having been previously "warmed up," the drive clutch was disengaged and the tunnel was brought to its lowest possible speed of about 2 mph. The conical taconite test surface was placed in position and the sampling system started. The tunnel clutch was then engaged and air speed was brought to 40 mph at pitot tube height in approximately one minute. Sampling continued for 60 minutes and therefore all data except the transient test data are one hour time average samples. The filters were stored in glass petri dishes and the nozzles were quantitatively backwashed with acetone. The total particulate sample weight was therefore composed of the filter weight gain portion and the nozzle backwash portion.

Transient Test Procedures

Everything for the transient tests were identical to the one hour time average samples except the filter heads were exchanged at the second downwind position with time. This involved recording volumes, recovering filters and backwashing nozzles in a very closely coordinated effort. In this way, the particulate concentration variation with time was determined.

RESULTS AND DISCUSSION

Steady State Measurements

The results from the one hour sampling time test series are presented in Tables 2, 3 and 4. Each table presents the concentrations in milligrams per cubic meter for each of the three downwind positions. The overall space and test-wise average is shown in a box to the lower right of each table. Note that copious replicate data is contained in Tables 2, 3 and 4. Nine particulate concentration values went into the dry taconite surface test average, twenty-seven into the dust suppressent tests and 13 for the water tests.

In addition, the various tests were conducted such that systematic errors would be minimized. For example, the test runs were mixed in time so that systematic errors were minimized. The test run numbers increase with calendar time. Test run one corresponds to Sunday, March 2, and run 18 to Friday, March 28, 1980.

In viewing the data, it becomes very apparent that the overall average downwind particulate concentration is lowest for the dry conical test surface. The dry surface resulted in a 2.63 mg/m^3 downwind average concentration while the test surfaces treated with suppressing agents averaged 7.80 mg/m^3. The dust suppressing agents were all mixed at a dilution ratio with fresh tap water of 1 in 1000. The amount of agent added to the pile resulted in a 1.1% pellet moisture content by weight.

There appears to be a trend regarding the most effective suppressing agent, however. Note in Table 3 that the use of agent "C" resulted in the lowest downwind particulate concentration of 6.15 mg/m^3. Agent "B" was 8.12 mg/m^3 and agent "A" 9.13 mg/m^3.

TABLE 2 Downwind particulate concentration from a dry taconite test surface

(Wind Speed = 40 mph)

(1 hr. sampling time average)

	L/D[a]			
Test No.	1.6 mg/m^3	2.7 mg/m^3	4.8 mg/m^3	AVG.
1	0.78	3.48	1.52	1.93
4	4.86	3.50	2.30	3.55
5	3.25	2.74	1.28	2.42
AVG.	2.96	3.24	1.7	$\boxed{2.63}$[b]

a. L is downwind distance from pile centerline to sampling nozzle inlet.

D is pile diameter at the elevation of nozzle.

L/D is not a scaling parameter to be applied to a full scale situation, it is being used for convenience.

b. All values corrected for background particulate which in most cases was negligible.

TABLE 3 Downwind particulate concentration from a taconite test surface composed of pellets treated with dust suppressing agents

(Wind Speed = 40 mph)

(1 hr. sampling time average)

Test No.	Dust Suppressing Agent[b]		L/D[a]		AVG.	Agent Average
		1.6 mg/m^3	2.7 mg/m^3	4.8 mg/m^3		
6	A	9.35	12.40	7.00	9.59	9.13
15	A	11.55	11.25	10.35	11.05	
16	A	6.45	7.08	6.72	6.75	
3	B	8.60	9.57	5.33	7.80	8.12
7	B	8.02	8.82	6.90	7.91	
14	B	7.12	11.35	7.44	8.64	
8	C	7.36	9.21	6.62	7.73	6.15
17	C	5.28	6.86	6.03	6.06	
18	C	4.19	4.62	5.20	4.67	
AVG.		7.55	9.02	6.84		$\boxed{7.80}$ [c]

a. L is downwind distance from pile centerline to sampling nozzle inlet.

D is pile diameter at the elevation of nozzle.

L/D is not a scaling parameter to be applied to a full scale situation, it is being used for convenience.

b. Amount applied such that resultant pellet moisture content approximately 1% by weight. All suppressing agents diluted in fresh tap water to 1 in 1000.

c. All values corrected for background particulate which in most cases was negligible.

TABLE 4 Downwind particulate concentration from a taconite test surface using Indiana tap water[b] as a dust suppressant.

(Wind Speed = 40 mph)

(1 hr. sampling time average)

	L/D[a]			
Test No.	1.6 mg/m^3	2.7 mg/m^3	4.8 mg/m^3	AVG.
2	9.13	11.2	9.1	9.81
9	8.53	8.90	8.57	8.67
10	4.17	8.83		6.50
11	5.63	9.66		7.65
13	8.54	10.06	7.8	8.80
AVG.	7.20	9.73	8.49	$\boxed{8.47}$ [c]

a. L is downwind distance from pile centerline to sampling nozzle inlet.

D is pile diameter at the elevation of nozzle.

L/D is not a scaling parameter to be applied to a full scale situation, it is being used for convenience.

b. Amount applied such that resultant pellet moisture content approximately 1% by weight.

c. All values corrected for background particulate which in most cases was negligible.

From Table 4, the use of water only as a dust suppressing agent resulted in a downwind particulate concentration of 8.47 mg/m^3. The amount of water added and the procedure used to spread it over the pellets was identical to that of the suppressing agents. For all water only tests, the average pellet moisture content was 1.07%.

There appears to be a significant difference between a dry taconite surface and a surface which has been treated with suppressing agent and water or water only. The dry taconite surface fugitive dust concentration is significantly lower than the suppressing agent surface or the water only treated surface.

Further, it appears that the suppressing agent and water mixture (Table 3) are no better in reducing fugitive dust than a surface treated with water only. The suppressing agent surface resulted in a downwind concentration average of 7.80 mg/m^3 while the water only treatment was 8.47 mg/m^3.

A graphical display of the same data presented in Tables 2, 3 and 4 is in Figures 6, 7 and 8. From these plots the differences between the suppressing agent and water only treated surfaces to the dry surface are clearly evident. The variation with distance in downwind concentration is due to the nature of the aerodynamic flow around a cone. The greater variability in concentration at the 1st downwind measurement station (L/D = 1.6) as compared to the 2nd (L/D = 2.7) and 3rd (L/D = 4.8) is also due to the nature of the aerodynamic flow over and around a cone. The 1st downwind sampling nozzle is located in the downwind aerodynamic cavity of the cone and the resulting turbulence and vortex shedding causes the concentration variation to be greater than that at the two further downwind stations.

Note also that the 2nd downwind station has slightly higher concentrations than either the 1st or 3rd measuring station. This effect is due also to the nature of the flow over and around a conical form and cannot necessarily be extrapolated to a full scale taconite piles since they are in essence elongated cones.

The foregoing results were not expected from these tests. Intuitively, it was expected that the dry pile would yield the highest downwind particulate concentrations with the water only and suppressing agent mixed with water following in decreasing concentration. However, the repeated concentration values for each test series are supportive of the statements made in reference to each test. Further testing was therefore undertaken to elucidate the nature of the particulate release from the taconite surface. The further tests conducted were transient as compared to steady state and support a particulate release hypothesis that is covered in the next section.

Transient Measurements

A series of three transient tests were performed to determine the time dependency of the downwind particulate concentrations from the taconite test surface. From these tests three plausible theories are suggested to explain the higher particulate release rates for wetted and then dried taconite pellets.

Figure 6. Downwind particulate concentration from a dry taconite test surface.

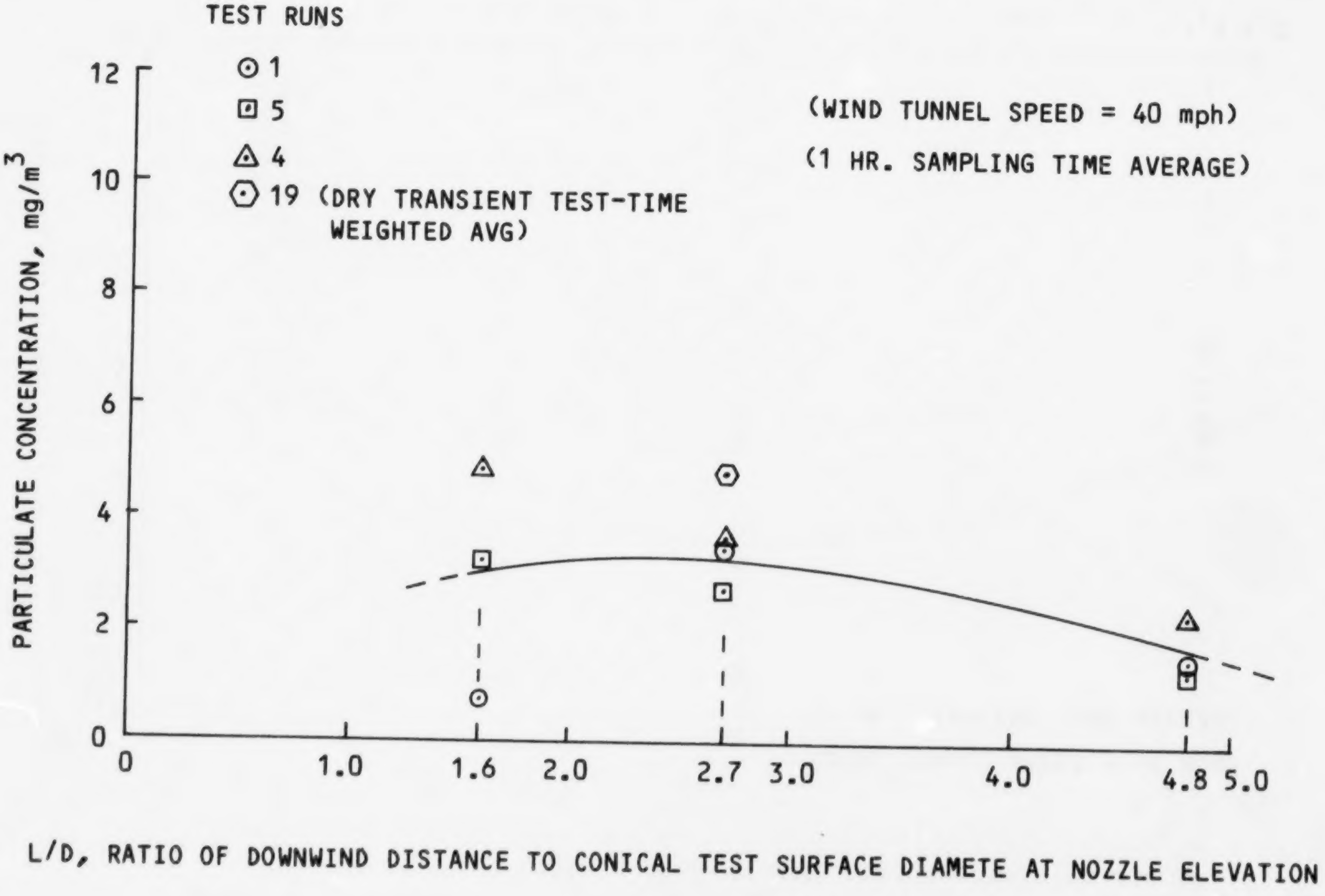


Figure 7. Downwind particulate concentration from a taconite test surface composed of pellets treated with dust suppressing agents.

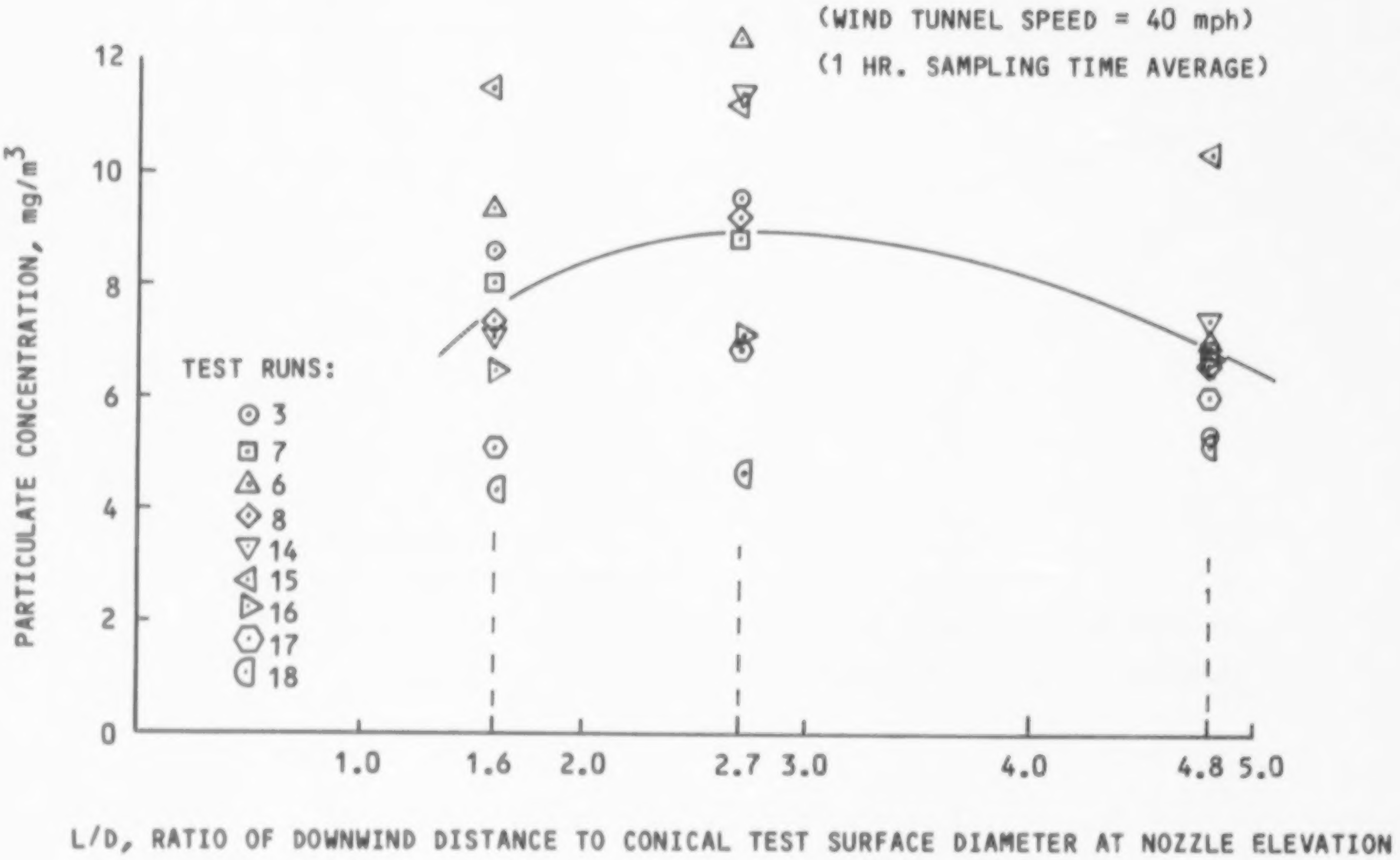


Figure 8. Downwind particulate concentration from a taconite test surface using Indiana tap water as a dust suppressant.

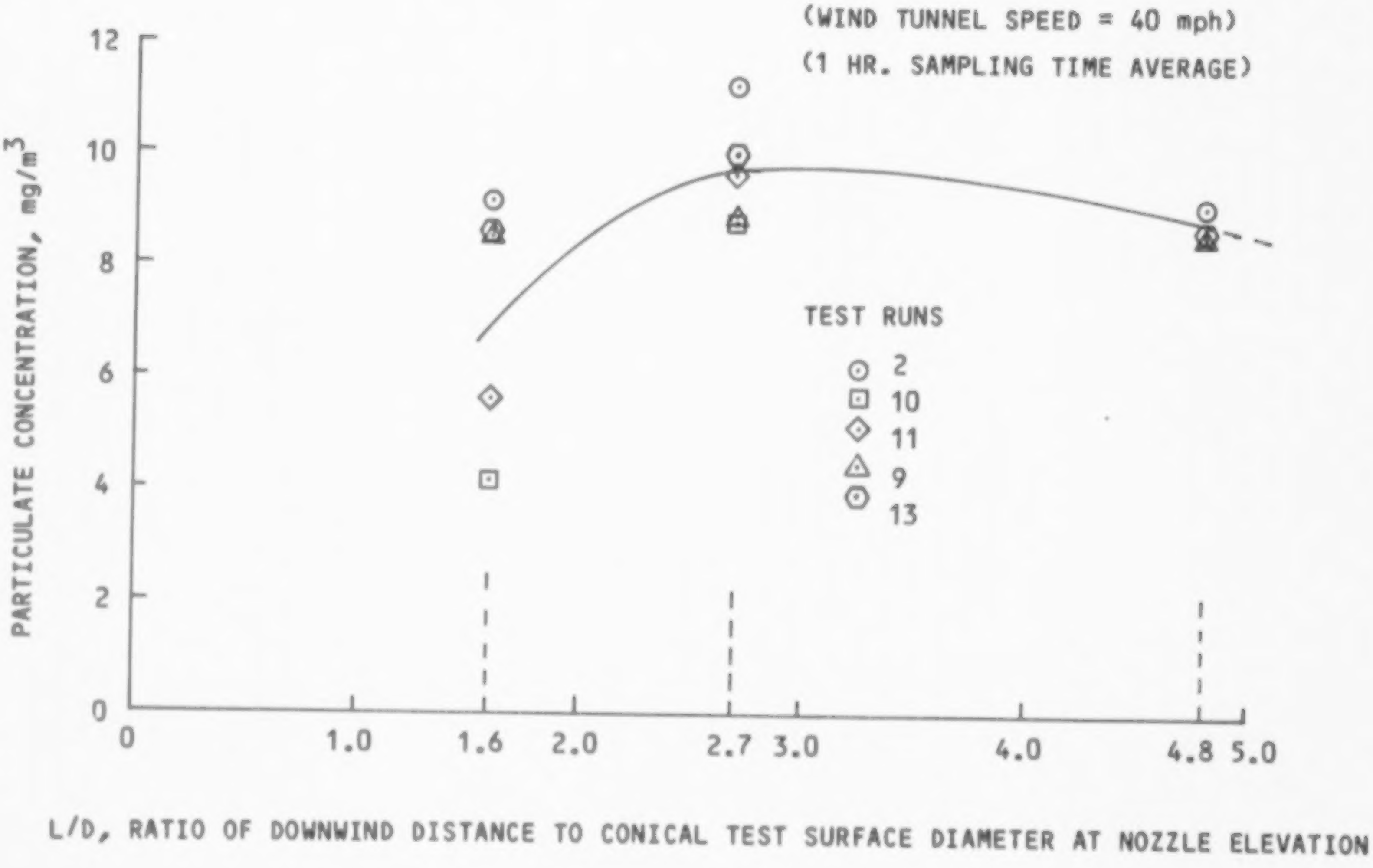


Table 5 contains the downwind particulate concentration data and the corresponding time into the one hour test. The test was conducted by placing the wetted taconite test surface (1.1% moisture by weight) into the wind tunnel, initiating particulate sampling, then bringing the tunnel up to 40 mph. The sampling nozzles were quickly interchanged at downwind sampling sampling position no. 2 as time into the test increased. The tests were terminated after 60 minutes. A plot of the data is seen in Figure 9. A sharp increase in particulate concentration is seen within the first 1.5 minutes then a rapid decrease at 4.5 minutes beyond which the concentration increases rapidly once again at 5 minutes. The peak value of the second increase is much lower than the first. Beyond 5 minutes, the particulate concentration exponentially decays until at 60 minutes into the test, the concentration appears steady state and approaching that value seen earlier for the dry pile concentration of 2.63 mg/m^3.

The rapid increase seen within the first 1.5 minutes is due to relatively large material as examination of the filter pads revealed. This large particulate is probably loosely held to the taconite pellet surface and is mechanically removed by the action of the wind. Next, the surface of the pellet begins to dry as the surface moisture is evaporated. Since the initial large particles are quickly removed by wind action (within first 1.5 minutes at 40 mph), the concentration sharply decreases between 1.5 minutes and 4.5 minutes. By this time (4.5) subsurface drying is now occuring with the water vapor proceeding through the interstices of the pellet material. This subsurface evaporation appears to trigger a rapid increase in particulate emissions between 4.5 minutes and 8.5 minutes into the test which may be due to the water vapor entraining fine particulate matter. Beyond this time the particulate concentrations exponentially decay out to 60 minutes. The decay approaches the steady state dry pile test previously shown in Table 2 of 2.63 mg/m^3.

Subsequent to the initial release of the large particulate at 1.5 minutes three theories are suggested for the particulate emission behavior.

1) As the subsurface drying occurs, water vapor off-gases through the interstitial pellet material carrying with it fine particulate matter.
2) The absorption of the water chemically reacts with some unknown constituent such as a calcium rich material which after firing could be CaO (hydrated lime) which is water soluble. In essence the water weakens the bond between pelletized particles causing higher particulate release rates.
3) The drying of the pellet surface causes "micro-spalling" of the pelletized material thus releasing more particulate.

The decay portion of the curve in Figure 9 is explained by a finite amount of material that is being removed from the pellet. In the limit, therefore, the curve should decay to the dry taconite surface downwind concentration. Recall that the 60 minute time average concentration shown in Table 2 for dry taconite was 2.63 mg/m^3. The decay curve of Figure 9 is obviously approaching this value in the limit.

Note also in Figure 9 that a curve is shown for a dry taconite surface. This test was run to confirm that the dry taconite surface is lower in fugitive emission at 40 mph than one which has been wetted and allowed to dry. Table 6 contains the dry transient data. As expected the initial release of loose sur-

TABLE 5 Particulate concentration variation with time for taconite test surface composed of pellets wetted with Indiana tap water[a].

(Wind Speed = 40 mph)

Test Numbers	Particulate Concentration at L/D = 2.4 mg/m^3	Time into test (midpoint of sampling time interval) minutes
10, 11, 12	32.45	1.0
	46.40	1.5
	37.00	2.5
	8.97	3.5
	2.94	4.5
	25.50	5.0
	19.90	5.0
	16.50	8.5
	12.10	12.0
	9.71	16.0
	14.30	15.5
	8.83	25.0
	8.87	27.0
	5.03	38.0
	5.00	40.5
	5.61	49.0
	1.86	56.0
	3.84	60.0

a. Amount of water added such that resultant pellet moisture content approximately 1% by weight.

TABLE 6 Particulate concentration variation with time for a dry taconite test surface[a].

(Wind Speed = 40 mph)

Test Number	Particulate Concentration at L/D = 2.4 mg/m^3	Time into test (midpoint of sampling time interval) minutes
19	56.73	1.0
	25.31	3.0
	25.02	5.0
	4.74	7.0
	0.83	12.0
	0.24	23.0
	3.15	37.5
	0.71	52.5

a. No water or agent added to pellets

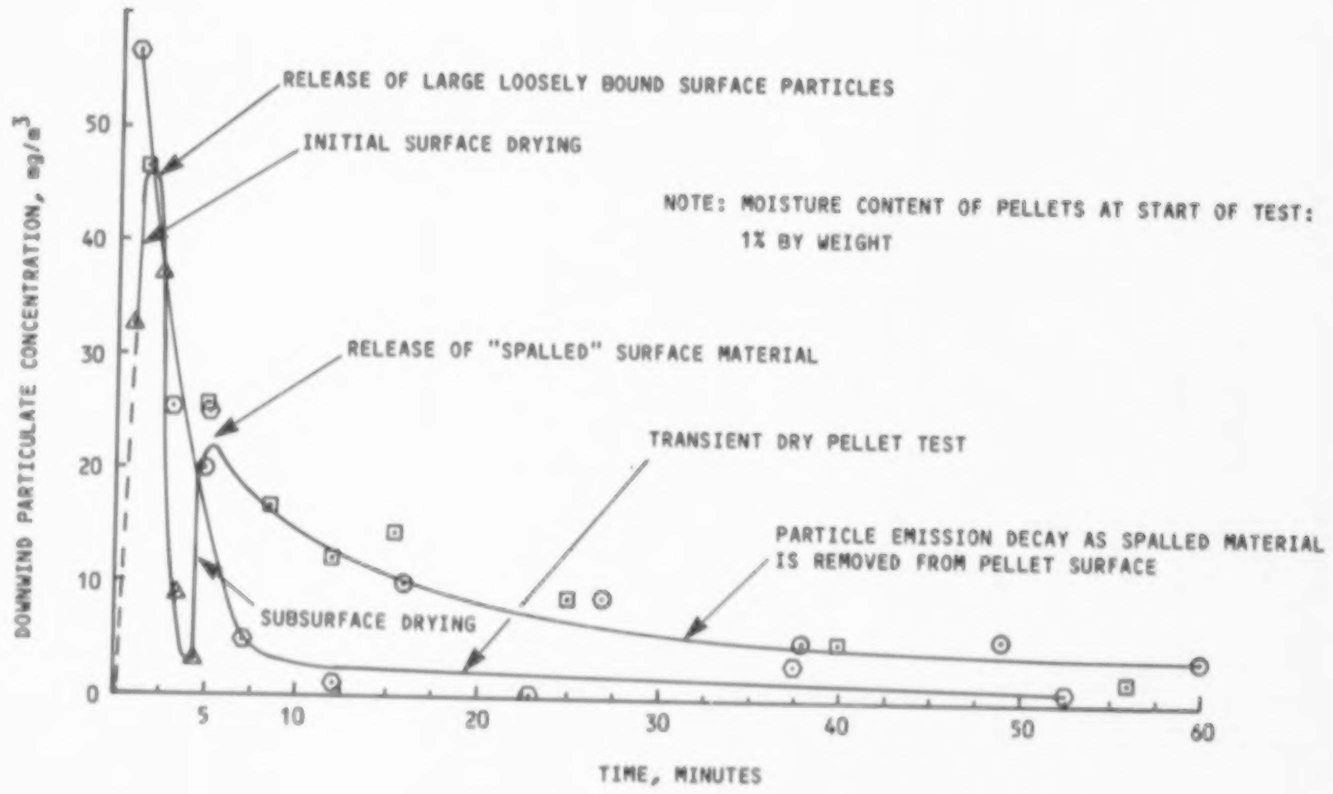


Figure 9. Transient particulate emission characteristic from wetted taconite test surface at 40 mph and a dry taconite test surface.

face particulate results in the high 56.73 mg/m^3 concentration after only 1.0 minute. After 7 minutes, however, most of this fine particulate is gone and the dust concentration drops to 4.74 mg/m^3. Beyond this point, the concentration is very low compared to the wetted and drying surface.

CONCLUSIONS

1) A dry taconite surface when exposed to a vertical wind profile from 20 to 40 mph results in a substantially lower downwind particulate concentration than one which has been wetted and then allowed to dry.

2) Of the three commercially available dust suppressing agents tested at a dilution ratio of 1 to 1000, one agent appeared to be more effective than the others. The more effective agent reduced the downwind particulate concentration by 33% over the least effective agent.

3) Using three commercially available dust suppressing agents diluted 1 in 1000 with Indiana tap water appear to be no better than using water only to suppress dust from a taconite pellet surface. Water resulted in a dust concentration of 8.47 mg/m^3 and suppressing agent 7.8 mg/m^3.

4) The taconite surface when wetted either with water only or a suppressing agent mixed with water at a dilution ratio of 1 in 1000 causes about 3 times higher particulate concentrations than a dry pile with no agent whatever applied.

5) The transient release of particles from a wetted surface appears to be strongly related to the use of water. The water somehow causes the surface of the pellet to become much more susceptible to the release of particulate matter.

6) When water is used to control fugitive dust from a taconite surface, the surface must not be allowed to dry but be continuously wetted.

COMPUTING DESIGN CHARACTERISTICS FOR COAL PILE DRAINAGE TREATMENT

Presented at the Fourth Symposium on Fugitive Emissions:
Measurement and Control
May 28-30, 1980
Monteleone Hotel, New Orleans, Louisiana

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ABSTRACT

Under Section 304(e) of the Clean Water Act, the U.S. EPA is developing a program of Best Management Practices (BMP's) for control of toxic and hazardous discharges from ancillary industrial sources. These sources include plant-site runoff, spills and leakage, sludge or waste disposal, and raw-material drainage.

For many electric utilities, BMP means evaluating coal storage piles with regard to the quantity and quality of storm related and dry weather drainage. Coal pile drainage is usually characterized as acidic with concentrations of trace metals, iron, sulfur, and solids.

TRC is developing a mathematical model to simulate coal pile drainage for the design of appropriate treatment systems. The model will allow for the consideration of various antecedent meteorological conditions including rain and snow precipitation, freeze-thaw phenomena, and air temperature. Other hydrologic phenomena the model will evaluate are:

- pile runoff
- snowmelt
- percolation through the pile
- infiltration into groundwater
- evaporation

The model will also simulate coal pile runoff quality. Components included are framboidal pyrite oxidation, acid production, and the subsequent release of trace metals.

TRC will discuss how its model is one available method to characterize coal pile runoff under varying meteorological conditions. TRC is currently developing an extensive field program at a number of utilities to calibrate and verify the model.

1.0 INTRODUCTION

Current practice to compute design characteristics for coal pile runoff treatment may be overly conservative and unnecessarily costly. Accepted practice dictates that storage/treatment be designed to accomodate all of the runoff from a 10 year-24-hour storm. EPA-sponsored[1] studies completed by TRC in 1976 at utility power plants in Pennsylvania suggest that while initial stormwater runoff contains relatively high levels of contaminants, the pollutant concentrations decrease rapidly as the storm progresses. Why, then not store and treat the initial "dirty" runoff and bypass the subsequent "clean" water if it meets NPDES limits?

This concept has captured the interest of the Utility Industry. The industry through UWAG, EEI, and EPRI is presently participating in a joint EPA-Utility Industry-TRC project to develop mathematical modeling and monitoring techniques that can be used to characterize coal pile runoff on a dynamic basis for a storm event. This project has started where the previous EPA-TRC efforts left off.

This paper will discuss the conclusion of previous coal pile drainage monitoring efforts, and the objectives of the current EPA-utility program including the development of a mathematical model for coal pile drainage and the related field program for calibration and verification of the model.

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[1] Brookman, Binder, Wade, "Sampling and Modeling of Non-point Sources at a Coal-fired Utility", EPA - 600/2-77 - 1979, September 1977.

2.0 PREVIOUS COAL PILE RUNOFF PROGRAMS

In 1976 coal pile runoff was investigated by TRC for two steam electric generating stations in Pennsylvania-Warren Station of Pennsylvania Electric Company and Portland station of Metropolitan Edison Company.[1]

At each site, a network of sampling stations was established to collect coal pile runoff during the duration of several storms and the intervening dry periods. Samples collected were analyzed for pH, sulfate, alkalinity, total and dissolved solids, acidity, total iron, aluminum, and manganese.

Several interesting observations were made during the field program.

1) The seepage from the base of the coal pile after the storm event was orders of magnitude more concentrated than the wet weather runoff stream.

2) At the beginning of the storm, a "first flush" with higher pollutant concentrations could be seen. Through the rainfall period these values generally declined. For example, acidity levels on the September 17, 1976 storm at Warren Station were initially 3200 μg/l and declined throughout the storm. When the rain ended five hours later the acidity was 500 μg/l.

Tables 2-1 and 2-2 show analysis results from the Warren site. These two phenomena can be seen in the results.

The results of the 1976 field program were used to calibrate the SSWMM-Receiv II model developed by TRC for predicting the quantity and quality of stormwater runoff and its impact on receiving waters. The model results compared favorably with field measurements but identified several limitations in the SSWMM-Receiv II model. These limitations include the lack of capability to simulate storm erosion from material storage piles and to simulate stormwater percolation through material storage piles. With these limitations in mind, TRC outlined a scope of work to develop a model to better simulate coal pile drainage and a field program to verify it.

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[1] Brookman, Binder, Wade, "Sampling and Modeling of Non-point Sources at a Coal-fired Utility", EPA - 600/2-77 - 1979, September 1977.

TABLE 2-1

CHARACTERISTICS OF COAL PILE RUNOFF
DURING SECOND STORM EVENT AT
WARREN STATION OF PENNSYLVANIA ELECTRIC CO., WARREN, PA.
17 SEPTEMBER 1976

TIME	POLLUTANT (mg/l)							
	COAL PILE RUNOFF							DISCHARGE FLOW RATE lpm (gpm)
	TSS	TDS	SO_4	FE	Al	MN	ACIDITY	
1000 - 1015 - Rain Start	9800	4600	2300	900	100	40	3200	22 (5.8)
1015 - 1030	4200	3300	2300	-	-	-	2600	
1030 - 1045	6400	2400	1600	700	90	10	3100	
1045 - 1100	11400	2400	1800	1400	70	10	2000	
1100 - 1115	5000	2500	2100	700	80	10	2200	20 (5.3)
1115 - 1130	1700	3700	2100	500	-	-	2900	
1130 - 1200	1400	3800	2700	-	-	-	-	20 (5.3)
1200 - 1230	1600	3100	1700	300	-	-	-	
1230 - 1300	1700	3000	1000	200	-	-	-	
1300 - 1330	1700	-	-	-	-	-		
1330 - 1500 - Rain End	23000	500	200	-	-	2	500	17 (4.5)

TABLE 2-2

CHARACTERISTICS OF COAL PILE LEACHATE-DRY WEATHER
AT WARREN STATION OF PENNSYLVANIA ELECTRIC CO., WARREN, PA.
AUGUST - SEPTEMBER, 1976

Date	Hours Since Last Rain	Pollutant Concentration, mg/l								Discharge Flow Rate lpm (gpm)
		TSS	TDS	SO_4	Fe	Al	Mn	Acidity	pH	
8/25/76	250	200	40,000	57,000	23,500	1,800	100	18,000	2.4	1.5 (.39)
8/27/76	17	18,700	82,600	45,000	14,000	1,400	70	27,000	2.1	1.5 (.39)
9/16/76	505	12	21,700	25,000	9,700	1,100	70	37,600	1.5	1.4 (.39)

3.0 OBJECTIVES OF THE CURRENT PROGRAM

As a part of the program to develop predictive measures and methodologies for fugitive emissions, EPA's Industrial Environmental Research Laboratory (IERL-RTP) has sponsored a study based on TRC's recommendations to develop a predictive model for coal pile drainage. This project was also of interest to utilities; hence, additional funding and support was provided by the Edison Electric Institute (EEI) with special emphasis by its Utility Water Action Group (UWAG). TRC has been working with a technical advisory group consisting of utilities, EPA and technical organizations to ascertain the utilities' needs in predictive methodologies for coal pile drainage treatment design.

The EPA - EEI program has several components currently funded:

1) Research and evaluate existing models in related fields and specify model modifications needed to simulate coal pile drainage.

2) Query the coal fired utilities as to the data available on coal pile drainage. Assemble results of utility questionnaire for distribution.

3) Develop model, evaluate parameter sensitivity and model shortcomings.

4) Develop a field program design to calibrate and verify the model.

The above phases were completed in May, 1980.

In the upcoming phases, the field program will be conducted, the model fine-tuned and modified, and a user's manual will be developed.

4.0 DEVELOPMENT OF A COAL PILE MODEL

Using the experience of runoff modeling in the Pennsylvania field program, and with input from the Technical Advisory Committee, TRC developed an outline of the physical/chemical phenomena to be contained in a coal pile drainage model. These are summarized below. The result of their inclusion was a continuous simulation model to predict the dry and wet weather flow quantities and characteristics.

4.1 Quantitative Phenomena

1) meteorology - hourly input of rain, snow, and air temperature
2) surface runoff
3) snowmelt
4) percolation through the coal pile, interflow from the sides of the pile

A schematic diagram of the coal pile hydrology for the model is shown in figure 4-1.

4.2 Qualitative Phenomena

1) pyrite oxidation, acid production
2) freeze-thaw cycles accelerating oxidation
3) gully erosion
4) coal pile washoff of pollutants
5) reactivity of trace metals

The methodology by which the phenomena are addressed in the model is described in the following section.

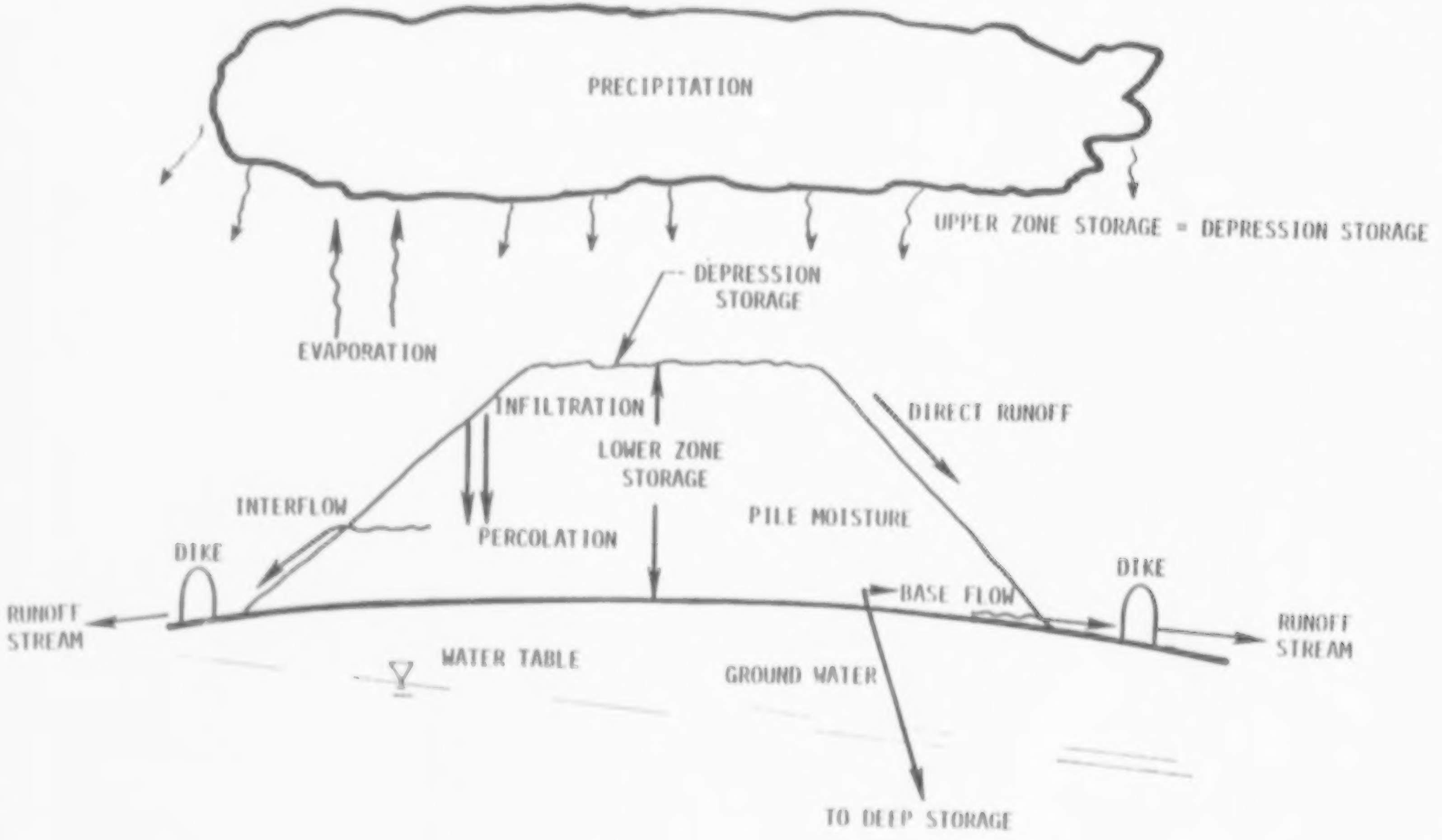
PRECIPITATION
UPPER ZONE STORAGE = DEPRESSION STORAGE
DEPRESSION STORAGE
EVAPORATION
INFILTRATION
DIRECT RUNOFF
LOWER ZONE STORAGE
INTERFLOW
PERCOLATION
PILE MOISTURE
DIKE
DIKE
BASE FLOW
RUNOFF STREAM
RUNOFF STREAM
WATER TABLE
GROUND WATER
TO DEEP STORAGE

FIGURE 4-1: SCHEMATIC OF HYDROLOGIC CYCLE COAL STORAGE PILE

5.0 MODEL DESCRIPTION

5.1 Base Model and Modifications

TRC investigated a number of runoff models to use as a base structure for coal pile drainage. These included SWMM, STORM, ARM, Stanford Watershed Model, and the Pyritic Systems model.

The Ohio State University version of the Stanford Watershed Model was selected as the base model because it was a continuous simulation with infiltration/percolation features. TRC utilized the 1977 version, made available through the Extraction Technology Branch of the U.S. EPA.

The OSU watershed model simulates the hydrologic cycle of a rural area. Features are included in the model for interception of rainfall by vegetation, transpiration, infiltration into the soil, percolation, evaporation, overland flow, soil moisture, depression storage, and ground water flow to deep storage.

OSU also developed a qualitative strip mine and refuse pile model to be used in conjunction with the OSU version of the Stanford Watershed Model.

Both OSU co-models required extensive revisions to contain all the physical/chemical phenomena discussed in Section 4. TRC deleted from the model a number of routines not applicable to coal pile drainage, such as those relating to vegetation. In addition, a number of the features were added to the model. These are listed below:

1) Addition of gully erosion to simulate the transport of solids from the sides of the pile.

2) Simulation of pyrite oxidation and acid production with the subsequent release of dissolved iron, sulfate, and trace materials during rainfall events.

3) Consideration of the acidity of rainfall and the alkalinity of coals.

4) Consideration of the impact of freeze-thaw cycles on the active coal surface area and subsequent pyrite oxidation.

5) Inclusion of a less complex snowmelt routine.

6) Modification of the meteorological input to allow the use of standard NOAA magnetic tapes of historical meteorological data.

5.1.2 Coal Pile Hydrology Model

TRC's coal pile hydrology model based on the OSU version of the Stanford Watershed Model is called TRCH2O.

TRCH2O considers rainfall infiltration, gully erosion, runoff, snow accumulation and snowmelt at the coal pile surface. In addition, moisture percolates through the pile to seep from the side of the pile, enter ground water beneath the pile, or to be emitted as seepage from the base of the pile.

TRCH2O uses a standard National Climatic Center magnetic data tape of hourly weather observations for a selected station as meteorological input. The data concerning the coal pile itself is input to the model by a small card deck.

5.1.3 Coal Pile Qualitative Model

TRC's version of the OSU strip mine and coal refuse pile model is called TRCCOAL.

TRCCOAL operates in either a dry day or wet day mode, depending on daily rainfall. On dry days, framboidal pyrite in the coal is oxidized producing acid, dissolved sulfate, and iron. The acid further reacts to dissolve trace materials in the coal. The number of freeze-thaw cycles during the preceding dry days accelerate the breakup of coal and the subsequent pyrite oxidation. Moisture is emitted from the lower zone of the coal pile as seepage.

During wet weather, dissolved materials are washed from the surface and to the other zones of the pile. They are then washed out of the coal pile to the runoff stream. The model then returns to its dry/wet day cycle.

The TRCCOAL model uses a tape created by TRCH2O for hydrologic data and a small card deck describing the characteristics of the coal pile.

6.0 MODEL OUTPUTS

6.1 TRCH2O

The quantitative model, TRCH2O, can be run without the qualitative component. It prints a tabular output of precipitation, runoff flows, and pile moisture data. The basic data is presented as daily flows and loadings for the year. After data analysis the user can choose output intervals at hourly or less intervals for a selected time interval. Some of the more detailed data is presented as user selected options. The output of TRCH2O is listed below:

Basic Outputs

1) A table of average daily rainfall in inches.

2) Summation of synthesized daily runoff rates, in cubic feet per second, for each month, followed by the annual total.

3) Synthesized monthly and annual totals for each of overland runoff, interflow, baseflow, and total flow, in inches.

4) Monthly and annual totals of liquid precipitation, in water equivalent inches, developed from the meteorological input.

5) Monthly and annual totals of frozen precipitation, in water equivalent inches, developed from the meteorological input.

6) End of month values, in inches, of pile, surface, and ground water moisture.

7) End of month values for indexes of ground water slope and pile depression storage.

8) End of month values for snowpack in water equivalent inches.

9) And annual balance, in inches, of unaccounted for moisture.

Optional Outputs

1) Echos all input data.

2) For one selected storm per year, prints values, in inches, of rainfall deposition, moisture storage, runoff origin, and runoff outflow for each time interval.

3) Prints daily values of selected variables to give a better indication of the program interactions in the upper, lower, and deep zones of the pile.

4) Echos recorded runoff flows, in cubic feet per second, for comparison with simulated flows.

5) Records the twenty highest clockhour rainfall events in the water year.

6) Prints daily pile moisture storage, in inches.

7) Prints daily values of the snowpack, snowmelt, and snowfall, in water equivalent inches.

8) Prints out average daily temperature in ^{o}F.

9) Prints out number of freeze-thaw cycles in preceding dry days.

10) Prints out simulated gully erosion of solids to the base of pile, in pounds per day.

11) Plots an arithmetic hydrograph for water year comparing recorded and simulated flows.

12) Plots an arithmetic hydrograph and rainfall hyetograph for selected data.

13) Prepares tape output file for use as input to TRCCOAL.

Plots of the annual runoff hydrograph are prepared by the model. An example output showing simulated runoff flow over the water year is presented in Figure 6-1. This hydrograph can also include recorded runoff flows for a comparison with the modeled values. An optional plot of the rainfall hyetograph and runoff hydrograph for a selected detailed storm is shown in Figure 6-2.

6.2 TRCCOAL

The co-model TRCCOAL calculates the amount of acid, sulfates, iron, and trace materials in the runoff stream and summarizes it on a daily, monthly, and annual basis. Below are listed the tables produced by TRCCOAL:

1) Daily loadings of acid, iron, sulfate, and trace materials in the direct runoff, interflow, and seepage, in pounds.

2) A calendar of simulated daily runoff flow volume, in cubic feet per second.

As in the hydrologic model, printouts of hourly data can be chosen for a selected time interval. In addition, the model produced plots of pollutant loadings. An example plot is shown in Figure 6-3.

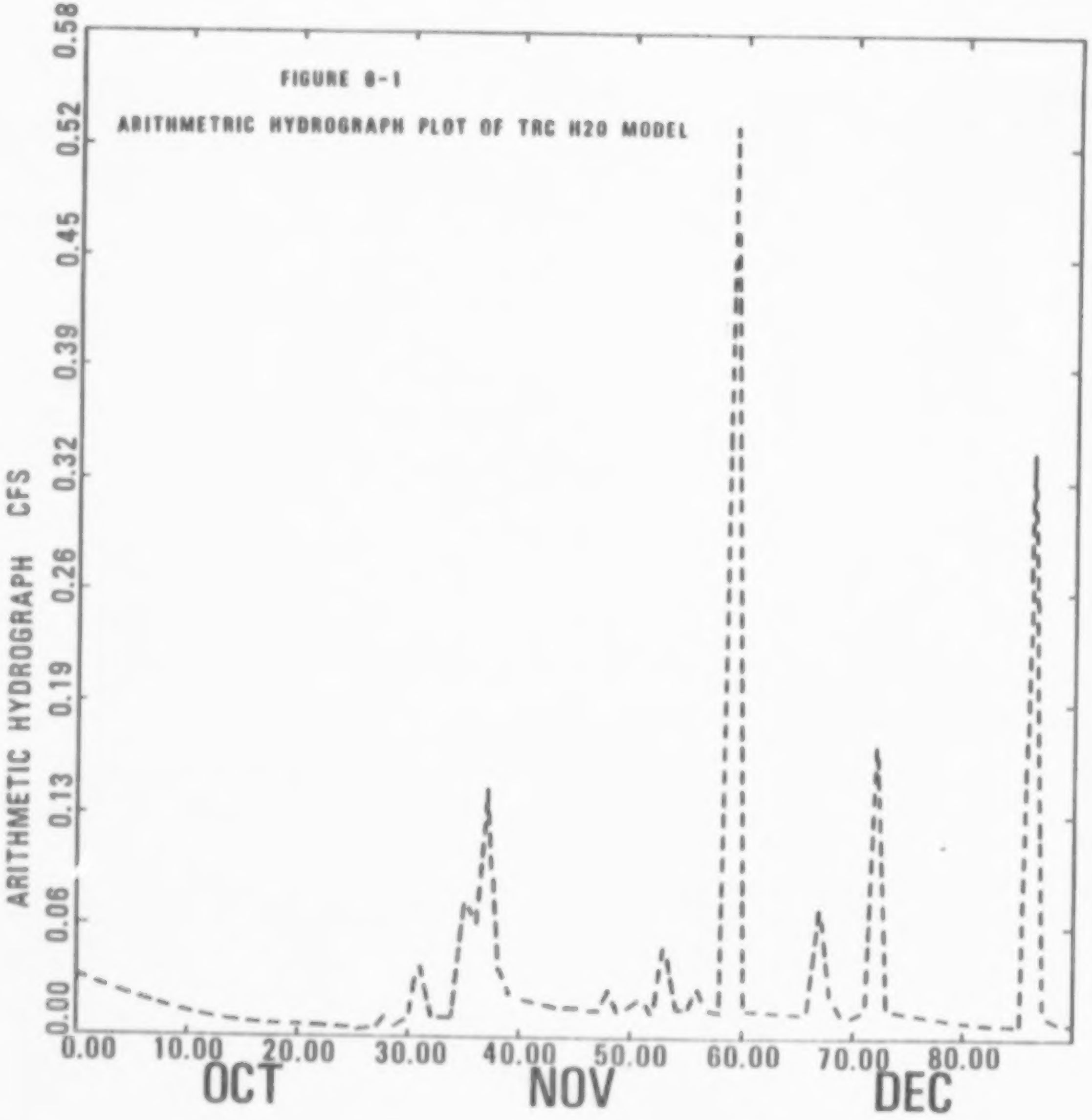

FIGURE 8-1

ARITHMETIC HYDROGRAPH PLOT OF TRC H2O MODEL

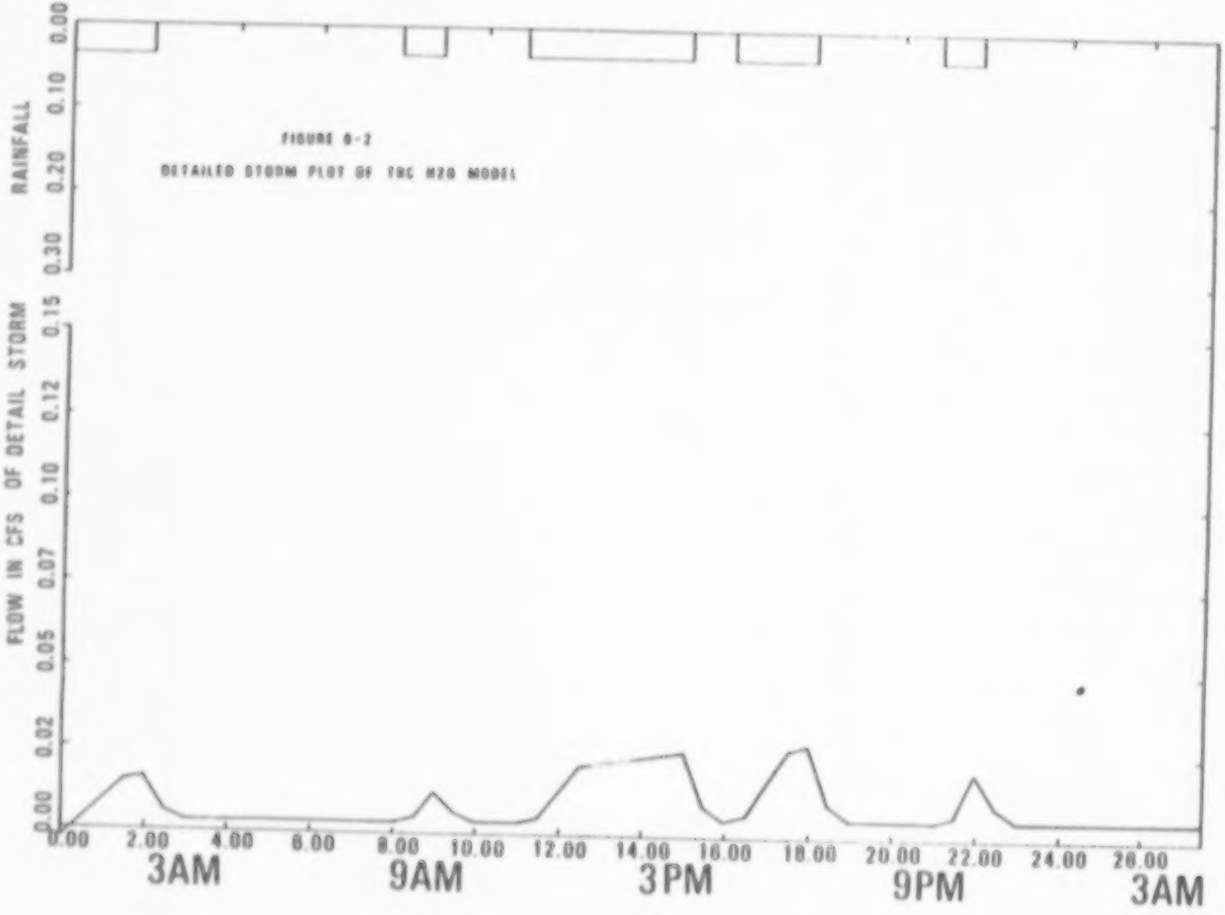

FIGURE 8-2

DETAILED STORM PLOT OF TRC H2O MODEL

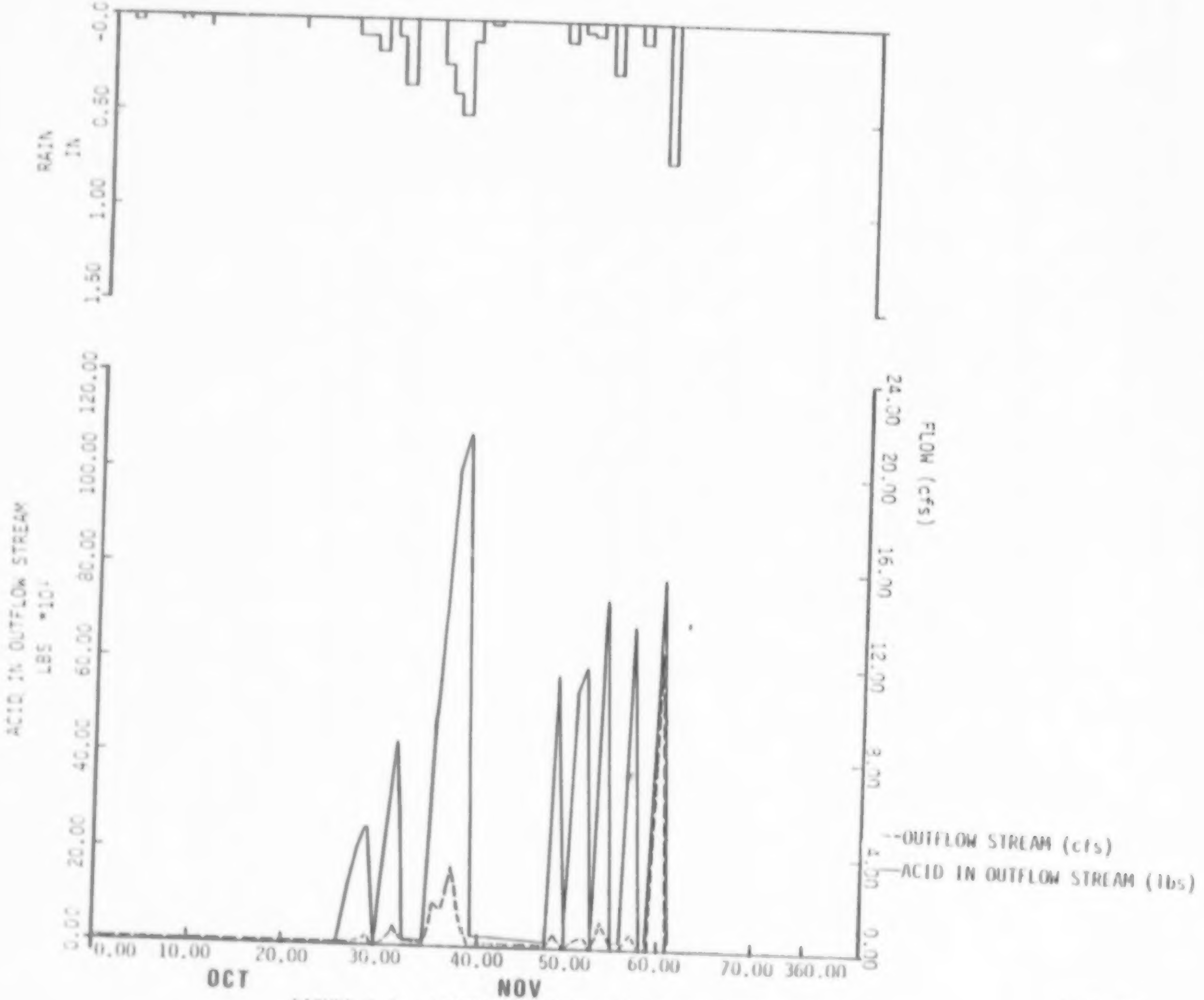

FIGURE 6-3: EXAMPLE PLOT OF QUALITATIVE OUTPUT

1316-005

7.0 DESCRIPTION OF FIELD PROGRAM AND INTERFACE WITH MODEL

7.1 Outline of Field Program

Following initial model development TRC will begin a phased field program for coal pile runoff from utility sites. The objectives of this program are:

1) To obtain representative data to fine tune and modify the coal pile runoff model.

2) To test the runoff model for a variety of climatic regimes, coal pile configurations, and coal characteristics.

3) To generate a substantial data base on the quantity and quality of coal pile runoff from various utility sites throughout the country.

The proposed field program will be conducted at 12 different utility sites nationwide over a 2 1/2 year period. The first two locations will serve as test sites and the data will be used to fine tune and modify the model. These two sites will also serve to refine the field program for the remaining ten sites. The field survey at the ten sites will be used to test the runoff model for a variety of climatic regions, coal pile configurations, and coal characteristics as well as generating a substantial data base on coal pile runoff. The field program for each site will vary from one month to 9 months.

7.2 Parameters of Interest

During the field program at each site, TRC will take continuous measurements of flow, pH, conductivity, and temperature.

In addition, samples will be taken of the runoff flow periodically and analyzed for acidity, alkalinity, TSS, TDS, TOC, sulfate, hardness, iron, and 19 trace metals.

A small meteorological station will be erected at each site to measure precipitation, air temperature, solar radiation and evaporation.

7.3 Data Reduction

All strip charts from the continuous monitors will be digitized to produce magnetic tapes of site data. The tape of the runoff flow volume can be read into the model to plot a comparison of simulated and recorded flows. All laboratory analysis will be reduced, evaluated statistically and placed on magnetic tape.

8.0 COMPUTING DESIGN CHARACTERISTICS

8.1 Data Bank

All of the data collected in the field program will become part of a computerized data bank. The data can be used by utilities which do not choose to simulate their coal pile runoff but rather would be interested in evaluating data from a site with similar coal pile characteristics. The data can be used to determine possible waste characteristics and volumes for treatment system design.

8.2 Coal Pile Drainage Model

The model, calibrated and verified under a number of field conditions, can be used to simulate different coal pile drainage situations. Using several years of historical meteorological data, the model can determine "average" flows and pollutant loadings. The model also has the option to read in selected precipitation data from a card deck. The user can create different combinations of dry days and storm events to evaluate when the highest pollutant loadings occur. In addition, the plots of detailed storms will show when and if the "first flush" of pollutants occurs and when runoff flow concentrations are low enough to be discharged without treatment.

From this analysis of both average and worst case conditions, collection basins and treatment works can be more accurately designed and sized.

9.0 SUMMARY OF UPCOMING ACTIONS

As of May 1980 TRC has completed initial model development, the field program design, and a manual of field procedures. TRC is working with interested utilities, EPRI, EEI, and EPA to locate test sites. Data from these field programs will be used in model calibration and verification. By the end of 1981 the model should be useable as a valuable predictive tool in coal pile drainage characterization.

EMISSIONS AND EFFLUENTS
FROM
RAIL AND TRUCK TANKCARS

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800 N. Lindbergh Blvd.
St. Louis, MO 63166

ABSTRACT

As many as 700 different commodities are handled by rail or truck tankcars. Approximately 37,000 railcars and 5,000,000 tanktrucks are cleaned each year by industry and service companies. Air emissions of hydrocarbons can be as high as 2.4 kg for tankcars and 310g for tanktrucks. Viscosity and volatility are the primary influencing factors on emissions.

If untreated, cleaning solutions from this process could exceed 2,500 metric tons/year of oil and grease in the wastewater. Hydrocarbon emissions to the air could also exceed 620 metric tons/year or about 0.0022% of U. S. emissions. Practical and economically feasible control for air emissions does not exist except for combustible gases and water-soluble vapors. State-of-the-art technology for wastewater effluents does exist but the effectiveness is widely variable and is very expensive.

This report describes the state-of-the-art practice in mobile tank cleaning. Composition, estimated quantities, and rate of emissions and pollutants are described along with control methods and costs.

INTRODUCTION

Various chemical and petroleum products are transported by rail tankcars and tanktrucks. These shipping tanks must be cleaned before being used to ship a different material, or contamination of the new material could result. An experimental study (1) was conducted by Monsanto Research Corporation to obtain preliminary estimates on air emission and water effluent from the cleaning process. This report assesses the impact and the economics of one potential control technology system.

Rail tankcars and most tanktrucks are in dedicated service (carrying one commodity only). Unless contaminated, they are cleaned only prior to repair or testing. Nondedicated tanktrucks, approximately 22% of the total tanktrucks in service, are cleaned after every trip to prevent cross contamination. The approximate total number of units cleaned per year are 37,000 rail tankcars and 5,010,000 tanktrucks.

Steaming, washing and/or flushing of the tanks result in air emissions and wastewater effluents. These cleaning operations are partially enclosed. Residual material is usually washed to the wastewater collection system, and only small amounts of material escape through the vents to the atmosphere.

Air emissions from cleaning of tanks are predominately organic chemical vapors. As hydrocarbons, these emissions represent less than .0022% of the national emissions of hydrocarbons. Water pollutants from cleaning of tanks are primarily oil and grease, suspended solids, and phenol. Uncontrolled water effluent quantities from this source are summarized in Table 1.

TABLE 1. POTENTIAL WATER POLLUTANTS FROM RAIL TANKCARS, TANKTRUCKS, AND DRUMS (metric tons/yr) (Estimated in reference #1)

Source type (basis)	Oil and grease	Suspended solids	Phenol
Rail tankcar cleaning (37,220 cars/yr)	830	4,100	31
Tanktruck cleaning (5,010,000 trucks/yr)	1,745	6,070	986

SOURCE DESCRIPTION

There are approximately 178,000 rail tankcars and 90,000 tanktrucks in service in the United States. Most of the tanks are owned privately and haul liquids. These privately owned tanks are not cleaned as often since they generally can be used for dedicated service. Leased tanks, on the other hand, are cleaned nearly every trip. The amount of cleaning that is conducted depends upon the operational practice of the cleaning site, the chemicals being removed, and the size of the tank. The quantities used per tank truck vary from approximately 0.23 cubic meters (sixty gallons) for steam operations to 20.9 cubic meters (5,500 gallons) for full flushing, with two cubic meters (500 gallons) being considered the average. The average amount of material cleaned from each tanktruck is estimated to be 100 kilograms. Vapors from volatile materials are flared at a few terminals, but the most common practice is to allow them to dissipate into the atmosphere.

The amount of liquid used per rail tankcar varies from 0.23 cubic meters for steam cleaning to 129 cubic meters (34,000 gallons) for total flushing of a large tank car. The average amount of residual material cleaned from a tankcar is estimated to be to 250 kilograms. Vapors from cleaning tank cars used to haul volatile materials are sent to flares at some cleaning facilities. Vapors of materials such as anhydrous ammonia and chlorine are dissolved in water and become waste water constituents. Vapors not flared or dissolved in water are dissipated into the atmosphere.

Tables 2 and 3 summarize the typical variety of chemicals cleaned from tanktrucks during a one-month period along with the frequency of the type of cleaning methods. The most common cleaning practice is the use of steam, although most commercial cleaners utilize a water rinse before and after the steam cleaning. As shown in Table 3, the determination of emissions and emission factors is complicated by the cleaning methods.

TABLE 2. TRAILER INTERNAL CLEANING GENERATION RATES FOR ONE TERMINAL DURING ONE MONTH OF OPERATION (2)

Method Number	Cleaning method	Water use, m^3/trailer	Number of trailers	Total water use, m^3
1	Cold water flush	0.57	84	47.6
2	Cold water flush--caustic/acid tank	8.3	321	2,666.0
3	Cold water flush--steam--cold water rinse	3.0	316	954.5
4	Cold water flush--spin/detergent--cold water rinse	1.1	123	139.3
5	MEK, MIBK,[a] or acetone solvent--cold water rinse	0.57	0	0
6	Styrene solvent--cold water rinse	0.57	0	0
7	Cold water flush--steam--cold water rinse--spin w/detergent--cold water rinse	3.6	68	243.9
8	Cold water flush w/Butterworth for dry bulk trailer	5.7	78	441.7
TOTALS			990	4,493.3

TABLE 3. COMMODITY/TANKTRUCK DATA FOR ONE TERMINAL DURING ONE MONTH OF OPERATION (2)

Cleaning method number[a]	Commodity	No. of trailers cleaned
1	Uran fertilizer	16
	PAPI--isozylate	2
	Ethyl chloride	10
	Alum	53
	Water for glue	2
	Water softener	1
2	Caustic soda (50%)	123
	Silicate soda	2
	Acetic acid	22
	Phosphoric acid	1
	Spent acid	47
	Sulfuric acid	87
	Hydrochloric acid	38
	Corrosive liquid	1
3	Solvent	18
	Toluene	26
	Xylene	2
	IPA--isopropyl alcohol	23
	Sodium MBT	1
	EDA--ethylene diamine	15
	DTA--diethylene triamine	8
	Poly amines	7
	Vinyl acetate	23
	Cyescal	3
	Phenol	32
	Alcohol	22
	Petroleum chemicals	1
	Peroxide	4
	Biphenyl	2
	Sodium bichromate	9
	Sodium methylate	3
	PA-phthalic anhydride	6
	Acetone	9
	Adaline	4
	Ferric chloride	3
	TTA--Amine 220	3
	AN--acrylonitrile	8
	Protein feed supplement	2
	Calcium chloride	1
	Styrene	2
	Methyl acrylate	1
	Weed killer	4
	Shell pan	1
	DMK--dimethyl ketone	4

TABLE 3 (Continued)

Cleaning method number[a]	Commodity	No. of trailers cleaned
3(cont.)	Benzene	1
	Pentylamine	1
	Ethylene glycol	3
	MEK--methyl ethyl ketone	14
	ITA	2
	Mineral spirits	3
	DAA--diacetone acrylonitrile	4
	NBA--normal butyl alcohol	1
	Methanol	3
	Butyl cellosolve	1
	Formaldehyde	24
	Oxylene	1
	Naphtha	1
	MIBK--methyl isobutyl ketone	4
	Demineralized water	1
	Turpentine	2
	Oxital--ethylene glycol monoethane ether	1
	TRI Clean D	2
4	Glue	72
	Paint	2
	Resin	30
	Water treating compound	5
	Coastal pale oil	7
	Petroleum oil	3
	Cotton oil	2
	Script set	2
7	Diesel oil	21
	Petrolatum	16
	Ink oil	2
	Strip oil	13
	Hi Boiler Oil	2
	Tall Oil	5
	Insulator oil (new)	1
	CPTIC--crude petroleum	8
8	Potash and fertilizers	
	Plastic pellets	78

[a] Cleaning method numbers correspond to those tested in Table 2.

AIR EMISSION

The great diversity of commodities (over 700 chemicals) carried by rail tankcars and tanktrucks makes it nearly impossible to sample and obtain emission factors for every possible material. Sampling of emissions from the cleaning of selected commodities was conducted to obtain an indication of the relative amounts of various types of materials. In order to achieve a representative picture, the organic chemicals were broken down into classes characterized by high, medium, and low viscosities and by high, medium, and low vapor pressures at ambient temperature. Viscosity affects the quantity of material which remains in the tank since low viscosity materials would drain more easily than high viscosity materials. It was anticipated that the higher the vapor pressure the higher the air emission rate would be during cleaning.

It has been reported that virtually all the air and water pollutants are removed from the tank during the first washing cycle. This takes 45 minutes to one hour for tank trucks and one to two hours for rail tankcars. Subsequent rinsing adds only small (less than 2%) quantities of waste to the wash water. The measured emissions from tankcar and tanktruck cleaning are summarized in Table 4. Using these data and a Gaussian dispersion model, the impact of a typical cleaning facility on ambient air quality can be estimated. In its simplest form, the dispersion model for the calculation of the maximum ground level concentration is (3):

$$X_{max} = \frac{2Q}{\pi H^2 e \overline{U}}$$

TABLE 4. MEASURED EMISSIONS FROM TANKCAR AND TANKTRUCK CLEANING

Compound	Chemical class: Vapor pressure	Chemical class: Viscosity	Total emissions, g[a]	Measured emission concentration, mg/m^3
Acetone	High	Low	311/truck	654
Perchloroethylene	High	Low	215/truck	526
Methyl methacrylate	Medium	Medium	32.4/truck	79.1
Phenol	Low	Low	5.5/truck	14.0
Propylene glycol	Low	High	1.07/truck	4.3
Ethylene glycol	Low	High	<0.32/car	<0.2
Chlorobenzene	Medium	Medium	15.7/car	8.8
o-Dichlorobenzene	Low	Medium	75.4/car	94.3
Creosote	Low	High	2,350/car (8-hr)	118

[a] Total emissions = (emission rate) x (emission volume).

where: Q = mass emission rate, g/s

$\overline{U}$ = U. S. average wind speed, 4.47 m/s

H = emission height, m

e = 2.72

π = 3.14

Since the average emission height is about four meters, the maximum ground level concentration for each chemical would be as shown in Table 5. These maximums are based on cleaning thirty tanktrucks or five and one-half tankcars each day. It is rare for more than one truck or car to contain the same chemical in any one day. Each maximum ground level concentration shown in Table 5 represents the worst case for a typical facility (cleaning only one chemical over a long period of time). In addition, this maximum can be shown to occur within twelve to forty meters from the tank being cleaned.

The concentration at the plant boundary would be considerably less than the maximum value since concentration decreases by the inverse of the square of the distance from the source. Compared to the ambient air quality standard for three hours of 160 micrograms per cubic meter, the typical cleaning facility is not likely to result in a violation of the ambient air quality standard. A more rigorous analysis could be conducted utilizing the distribution of commodities cleaned at each facility. However, additional study was not warranted since the worst case analysis showed that the present impact is very small.

TABLE 5. MAXIMUM GROUND LEVEL CONCENTRATIONS FOR DIFFERENT EMISSIONS

Type of cleaning	Emission	χ_{max}, $\mu g/m^3$
Tank truck	Acetone	359
	Perchloroethylene	248
	Methyl methacrylate	37
	Phenol	6.35
	Propylene glycol	1.24
Rail tank car	Ethylene glycol	<0.14
	Chlorobenzene	7.14
	o-Dichlorobenzene	34.3
	Creosote	267

From another perspective, if the highest emission factor for tanktrucks and tankcars (acetone) is applied to all of the tanks cleaned, the total emissions of hydrocarbons for tanktrucks and rail cars would be 538 and 87 metric tons per year, respectively. This corresponds to less than .0022% of the total hydrocarbons emissions in the U. S. Based upon this evidence, it has been concluded that air emissions from the cleaning of rail tankcars and tanktrucks are not significant emission sources.

WATER EFFLUENTS

Waste water collected in a tank cleaning facility is subject to a great variability. Even with a good treatment system, it is difficult to treat to consistently acceptable levels. Table 6 summarizes the effluent characteristics of a slightly larger than average tanktruck cleaning facility. This facility is a forty-five cubic meter per day (12,000 gallons per day) demonstration plant funded by the U. S. EPA (4). Also shown in Table 6 are the approximate levels that have been achieved in the effluent of this experimental system. A schematic of the system is shown in Figure 1. Utilizing these data and other available information, an analysis was conducted on the uncontrolled effluent concentrations resulting from representative sources. A more detailed description of this analysis is given in Reference 1. The results, which are summarized in Table 7 show that the effluent concentrations are especially high for oil and grease, and phenol. Further analysis shows that the impact on typical receiving waters is minimal.

To estimate the impact of an effluent on water quality, the concept of source severity was developed. Source severity is defined as the pollutant concentration to which aquatic life is exposed, divided by an acceptable concentration. The exposure concentration is the fully-diluted receiving water concentration resulting from the source. The acceptable concentration is defined as the concentration at which it is assumed that an incipient adverse environmental impact occurs (usually the water quality criterion). Mathematically expressed, this is:

$$S = \frac{(V_D/V_R)\ C_D}{F}$$

where

C_D = concentration in raw effluent, g/m^3

F = fresh water criteria, g/m^3

V_D = volumetric flow rate of discharge, m^3/sec

V_R = volumetric flow rate of receiving waters, m^3/sec

S = dimensionless

TABLE 6. TREATMENT PLANT OPERATING RESULTS -- MATLACK, INC., SWEDESBORO, N.J. (4)

Parameter	Raw feed	Effluent
pH	10.5 to 12.5	6.5 to 8.5
Color units	Over 500	10 to 50
Turbidity, FTU[a]	Over 500	-[b]
COD, g/m^3	1,800 to 11,000	125 to 300
BOD_5, g/m^3	600 to 2,000	20 to 100
Oil and grease, g/m^3	110 to 350	0 to 1
Phenols, g/m^3	1 to 250	0.1
Suspended solids, g/m^3	300 to 1,300	-[b]

[a] Formazin turbidity units; a standard unit of turbidity based upon a known chemical reaction

[b] Data not reported.

TABLE 7. EFFLUENT CONCENTRATIONS FOR REPRESENTATIVE SOURCES

Source	Effluent concentrations, g/m^3 Oil and grease	Phenol	Suspended solids	Flow, m^3/day
Rail tank cars	2,005	75	10,025	61
Tank trucks	230	130	800	45

TABLE 8. SOURCE SEVERITIES FOR REPRESENTATIVE SOURCES

Source type	Source severity, s Oil and grease	Suspended solids	Phenol
Rail tank car	0.16	0.00033	0.062
Tank truck	0.014	0.000020	0.080

Table 8 is a summary of the severities for the effluents from a representative cleaning facility. From this analysis, the exposure concentration is found to be less than the fresh water criteria (severity < 1.0) even from the uncontrolled effluents into U. S. Average river flow (1).

The state total discharge rates of oil and grease, phenol, and suspended solids, assuming no treatment, were calculated by: dividing the production of the representative source into state production totals and multiplying this figure by the discharge rate per representative source. These quantities are given for each state in Reference 1. Table 9 summarizes the estimated uncontrolled emission burdens due to rail car and tank truck cleaning for selected states.

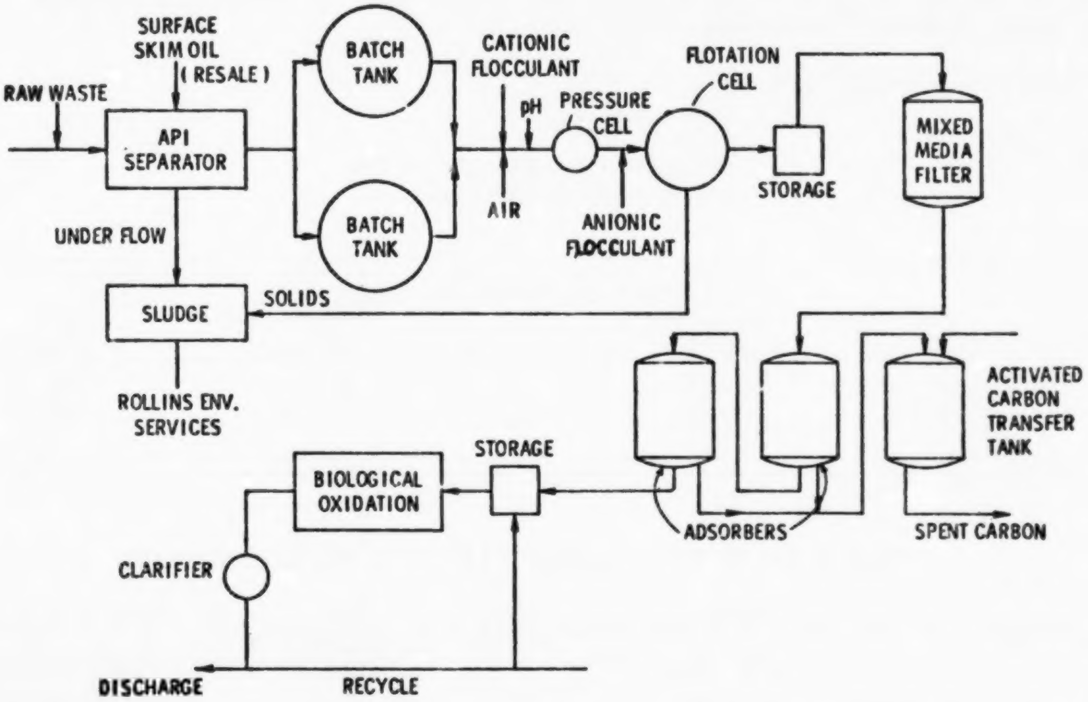
SURFACE SKIM OIL
(RESALE)
RAW WASTE
API SEPARATOR
BATCH TANK
BATCH TANK
CATIONIC FLOCCULANT
pH
PRESSURE CELL
AIR
ANIONIC FLOCCULANT
FLOTATION CELL
STORAGE
MIXED MEDIA FILTER
UNDER FLOW
SLUDGE
SOLIDS
ROLLINS ENV. SERVICES
ACTIVATED CARBON TRANSFER TANK
STORAGE
BIOLOGICAL OXIDATION
ADSORBERS
SPENT CARBON
CLARIFIER
DISCHARGE
RECYCLE

FIGURE 1. Wastewater Treatment System, Matlack, Inc., Swedesboro, New Jersey (4).

TABLE 9. PROJECTED RAIL TANKCAR AND TANKTRUCK CONTRIBUTION TO STATE EMISSION BURDENS

	Rail Tankcars				Tanktrucks			
State	Cars/yr	Oil and grease tons/yr	Suspended solids tons/yr	Phenol tons/yr	Tanks/yr	Oil and grease tons/yr	Suspended Solids tons/yr	Phenol tons/yr
Arkansas	3000	67	330	2.5	90,000	31	109	18
California	2000	44	220	1.7	240,000	84	291	47
Illinois	2000	44	220	1.7	290,000	101	351	57
Indiana	4750	106	530	3.9	220,000	77	266	43
Kansas	5000	110	560	4.2	172,000	60	208	34
Louisiana	2500	56	280	2.1	250,000	87	303	49
Ohio	1750	39	194	1.5	200,000	70	242	39
Texas	5500	120	610	4.6	400,000	139	484	79
U.S. Totals	37,220	830	4100	31	5,010,000	1745	6068	986

CONTROL TECHNOLOGY

This preliminary study indicates that control of air emissions from the cleaning of rail tankcars and tanktrucks is not necessary except for combustible gases and water soluble vapors such as ammonia and chlorine. Combustible vapors are usually sent to flares and burned. Vapors and materials such as chlorine are absorbed in water and sent to the wastewater stream.

Until the late 1960s, little attention was given to wastewater treatment in this industry. This inattention resulted because waters were generally low in volume, installations were small, and environmental impacts were considered relatively small in comparison to those of other sources. As shown in the source assessment (1), the severity of the wastewater effluents is quite small, especially in comparison to other industrial sources.

In recent years, several rail tankcar and tanktruck cleaning wastewater treatment facilities have been upgraded in an effort to meet environmental regulations. However, no installation is known to have a completely satisfactory treatment system. Treatment technology applicable to rail and truck wastewaters is for the most part well known. However, the wide diversity in the materials entering the wastewaters prevents the use of a single specific treatment system by all companies. For this reason, tank car and tanktruck cleaning companies are approaching their individual problems by using one or more combinations of conventional wastewater treatment methods.

Industry and tankcar manufacturers have developed new tank designs which avoid the necessity to clean the tank. Of particular interest is the recent development of diaphram tanks (5) which can carry a different cargo each way between plants. The diaphram prevents product contamination.

One tank truck cleaning facility has had some success in the treatment of a wide variety of chemicals in its wastewaters. However, their system, shown in Figure 1, has not been able to get the biological treatment to work, and problems still exist with the COD and BOD levels. The effluent concentrations obtained by this experimental facility are even higher than those obtainable with the same type of equipment on effluents from petroleum refineries. This indicates that the job of achieving comparable effluent concentrations will be much more costly and require further developmental work.

The costs of operating a system similar to the one shown in Figure 1 are summarized in Table 10. At present, this type of effluent cleaning system would cost about $25.00 per tanktruck and about $100.00 per rail tankcar.

TABLE 10. NET OPERATING COST (1975) FOR THE 45 CUBIC METER PER DAY (12,000 GPD) WASTEWATER TREATMENT FACILITY SHOWN IN FIGURE 1 (4).

	$/1000 gal
Labor - 1 operator, 9 hr/day - 5 days/wk	4.93
Carbon -	30.77
Chemicals - 90% cation polymer	3.85
Power -	0.77
Depreciation -	4.81
Sludge disposal - 40 gals/1000 gal wastewater	2.56
Biological oxidation -	2.31
TOTAL	50.00

CONCLUSIONS

This preliminary assessment indicates that (1) air emissions from the cleaning of rail tankcars and tanktrucks are higher for high vapor pressure. High viscosity materials will show higher emissions due to the amount of residual material and the cleaning method. (2) The emissions contribution to ambient air quality degradation is insignificant for the typical cleaning facility. The source assessment study shows that (3) waste effluents do not pose a major impact on the water quality, but that a reduction will be required to be compatible with effluent concentrations from other treatment processes. Finally, (4) the resulting cost, with existing technology, is high compared to the benefit. Wastewater treatment could be made potentially more effective by combining the stream to be treated with other wastewater, equalizing load to the treatment system. In addition, the use of diaphrams may reduce the amount of cleaning which will further reduce the present emissions and effluents.

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AV-TP-80/541

A NEW CONCEPT FOR THE CONTROL OF URBAN INHALABLE PARTICULATE BY THE USE OF CHARGED FOG

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ABSTRACT

This paper is directed to those scientists and engineers concerned with the control of fugitive particulates in the inhalable size range (< 15 μm) from non-traditional sources in the urban environment. A new type of electrostatically augmented spray nozzle (fogger) is described which is intended to achieve a target control efficiency of 90% for inhalable particulates. The theory of operation is explained, along with a physical model for predicting the control efficiency of the fogger. Results of preliminary wind tunnel tests are presented showing the degree of control actually achieved by the fogger for various operating modes. Finally, plans for additional modifications to the fogger are discussed which incorporate the information gained from preliminary testing in the wind tunnel.

Introduction

The use of electrostatic precipitation for the collection of fine particulate matter is common engineering practice and is well-documented in the literature.[1,2] More recently, electrostatics has been used to augment traditional wet dust collectors (scrubbers) of varying design[3,4,5,6,7]. Since 1977, one investigator at the University of Arizona has been studying a new approach for the application of electrostatically augmented water sprays (charged fog) on a bench scale for the control of fugitive dust generated by various industrial processes[8,9]. Commercial devices (foggers) resulting from this work are now available from a firm in Pennsylvania[10]. These foggers offer significant economic advantages over more traditional fugitive dust control technology, but also have problems which inherently limit both their effectiveness to control fine particulate and their applicability to control fugitive dust from certain types of sources. A more detailed discussion of these problems will be presented later in this paper.

In recent months, the health-related problems associated with suspended particulate matter in the inhalable size range (< 15 µm aerodynamic diameter) have been of rising concern. The U.S. Environmental Protection Agency plans to develop and promulgate a size-specific ambient air quality standard to address the inhalable particulate problem in the near future. If such a revised ambient air quality standard is promulgated, it will necessitate even greater degrees of control for nontraditional as well as traditional sources of particulate emissions, especially for those sources in the urban environment where the problem is most acute.

This paper will describe a new type of electrostatically augmented spray nozzle (fogger) for the control of urban inhalable particulate. The new fogger has been designed to eliminate the major operational problems associated with conventional equipment and is intended to achieve a target control efficiency of 90% for particulates in the inhalable size range. The Spinning Cup Fogger Thrower (SCFT), as it is called, will eventually be used to control emissions from mobile sources representing the major contributors to the inhalable particulate problem in the urban environment.

The following discussion presents the theory of operation and design of the SCFT, along with the results of preliminary wind tunnel tests conducted on the original prototype. A modified SCFT is currently under development which incorporates a number of design changes based upon the experimental data reported below and will likewise undergo detailed testing in the near future.

Theory of Operation

Experiments have shown that most dust is electrically charged and that generally the charge is negative[8]. By producing a positively charged spray, the dust particles are attracted to the water droplets, and the number of particles which the water drops will collect by impaction without electrical effect is increased substantially when the drops and particulate are of opposite charge. The agglomerated particles of mixed droplets and particulates will settle out according to the Stokes relationship.

A relationship describing the overall collection efficiency of suspended particulate matter by water droplets has been described by Calvert[7] and later by Cheng[11] and can be expressed as:

$$E = 1 - \exp\left[-\frac{3}{2} \cdot \frac{Q_l}{Q_g} \cdot \frac{t}{D_d} \cdot \eta\right]$$

where:

E = Overall collection efficiency
Q_l = Liquid volumetric flow rate
Q_g = Gas volumetric flowrate
t = Contact time (or characteristic length for the total capture process)
D_d = Sauter mean droplet diameter
η = Single droplet target efficiency

From the above expression it can be seen that the single droplet efficiency, η, is the most important determining factor in the control of fine particulates. The single droplet efficiency depends, to a large extent, on the unit mechanism, or mechanisms, by which the particles are captured, and which of these dominate. Such unit mechanisms include direct interception; inertial impaction; Brownian diffusion; and the electrostatic, magnetic, diffusiophoretic, and thermophoretic forces on the particles[7,11,12].

A detailed physical model has been developed by Grover and other collaborators for the scavenging of atmospheric aerosol particles by charged free-falling raindrops. It was determined that this model best describes the single droplet efficiency in terms of all the various capture mechanisms and forces involved[12,13,14]. The development of the model is quite complex and thus is being included in this paper by reference only.

Description of the Spinning Cup Fog Thrower

The SCFT consists of three main components, each serving a particular function. These components are a rotary atomizer, an ionizer, and a vane-axial blower. The rotary atomizer is comprised of a small hollow-shaft motor and spinning cup. Water from a low-pressure source is introduced into the hollow shaft and flows toward the other end where the spinning cup is mounted. Upon entering the rear of the cup the water stream strikes a rotating spider which deflects the water to the sides. A sheet of water then flows toward the lip of the cup where droplets are formed by centrifugal force, normally leaving the edge of the cup tangentially. The droplets are then charged by a stream of positive ions produced by an ionizer containing numerous small discharge needles. Current to the ionizer ring is supplied by a vacuum tube high-voltage DC power supply. The charged fog droplets are then deflected and projected forward by a flow of air supplied by the vane-axial blower into which the ionizer and rotary atomizer have been mounted. A diagram of the SCFT used during the wind tunnel tests described below is shown in Figure 1.

As was previously stated, the commercially available foggers have certain problems inherent in their design which not only limit their application to certain types of sources, but can also severely limit the degree of control achieved on fine particles. The first of these problems is that the existing foggers use either a standard pressure-type or twin-fluid nozzle to atomize the water, thus necessitating a substantial supply of high pressure water or air for proper atomization. In addition, these types of nozzles have a tendency to clog if the water supply contains a high concentration of suspended solids. This problem has been eliminated in the SCFT by a rotary atomizer which needs neither compressed air nor water pressure to generate a fog of fine water drops. In addition, a rotary atomizer is insensitive to any solids found in the water supply.

The second and more severe problem with existing equipment involves the type of charging mechanism being used. The existing foggers use an induction ring which tends to charge only those droplets on the outside of the spray cone during heavy sprays with the remaining droplets having little or no charge. Since the electrostatic attraction of dust to water droplet is critical to the efficient capture and agglomeration of fine particles, this is a significant problem. The SCFT solves the problem by using direct charging which effectively charges most, if not all, of the droplets generated by the atomizer, significantly increasing its potential to control particles in the inhalable size range. By these two basic modifications, the SCFT is expected to have greatly reduced water and power consumption over previous equipment, in addition to being able to more effectively control emissions from mobile sources.

Experiment

In order to verify theoretical relationships with experimental data, a series of tests were conducted in a 4-foot by 4-foot by 60-foot wind tunnel provided by the University of Arizona. A standard dust (AC Coarse) of known particle size and density was pneumatically fed into the entrance of the tunnel by a Vibra-Screw feeder and compressed air which was homogeneously mixed with the incoming ambient air by a diffuser cone. The SCFT was mounted approximately two equivalent diameters downstream of the tunnel entrance with the fog and air in cocurrent flow. Plexiglas viewing ports in both sides of the tunnel were provided at the discharge end of the fogger so that the wet/dry interface could be more closely observed. Two sets of sampling ports were provided in the front vertical wall of the tunnel; one set, approximately two equivalent diameters downstream of the discharge end of the fogger, was for determining charge/mass ratio and droplet size, and the other set at the far end of the tunnel was for determining particulate mass concentration and size. An axial blade fan pulled approximately 18,000 dscf/min of air through the tunnel. Figure 2 is a schematic representation of the University of Arizona wind tunnel.

To determine the control efficiency of the fogger under various experimental conditions, particulate samples were collected according to the test plan shown in Figure 3. A sample train was especially designed for this purpose to isokinetically extract a representative sample of particulate matter from the wind tunnel. The sample was later analyzed gravimetrically to determine both the total mass concentration and particle size distribution for each test scenario. This train consisted of a pitobe and associated inclined manometer connected by a flexible sample line to a horizontal elutriator. The elutriator was originally designed to have a 15 μm particle diameter cut-point (50% efficiency) at a flow of 20 scfm. Behind the elutriator was mounted a standard Sierra Instruments five-stage cascade impactor which discharged to a silica gel trap for the determination of moisture content. The flow was measured by an NBS-traceable Laminar Flow Element manufactured by the Meriam Instrument Company. The Laminar Flow Element was located downstream of the silica gel trap and connected to a standard Dwyer magnahelic gauge for reading differential pressure. The flow rate was metered by a large capacity needle valve located downstream of the Laminar Flow Element followed by a Cadillac centrifugal blower acting as prime mover. A photograph of the sampling train with the various components is shown in Figure 4.

For sample recovery, the front portion of the sample train and horizontal elutriator were rinsed with de-ionized water into separate plastic sample containers for transport back to the laboratory. There the liquid/particle mixture was quantitatively transferred to tared beakers and evaporated to dryness to determine the total mass collected. The samples were then resuspended in distilled water and deagglomerated ultrasonically. The particle size was determined by a Leeds & Northrup Microtrac Analyzer using a ruby laser and forward-scatter optical technique. The samples collected on the various cascade impactor stages were also analyzed gravimetrically using a standard analytical balance.

The charge-to-mass ratio was determined using a special sample train developed by AeroVironment according to a method provided by Dr. Hoenig at the University of Arizona. This train consisted of an insulated stainless steel probe tip mounted on a standard glass midget impinger. The probe was connected electrically to copper wool packing placed inside the midget impinger which also was connected by a shielded cable to an electrometer (Hewlett-Packard Model 425A) and associated strip-chart recorder. The impinger was immersed in a Dewar flask containing dry ice. A sample of fog droplets was then isokinetically extracted from the tunnel through the sample ports at the discharged end of the fogger. As the droplets moved through the impinger they were condensed out of the gas stream and frozen, thus transferring their charge to the copper wool packing. The charge was then measured by the electrometer and recorded by the chart recorder. The mass of water collected in the impinger was then determined gravimetrically at the end of each test run using a portable triple-beam balance. Isokinetic conditions were maintained by a Hastings mass flowmeter and needle valve with a standard diaphragm pump acting as prime mover. A standard pitot tube and associated inclined manometer were mounted next to the impinger/Dewar flask assembly with adequate distance between them to avoid aerodynamic interference.

The size of the droplets was measured simultaneously with the charge-to-mass ratio by a KLD Model DC-2 droplet counter. This unit uses a hot-wire technique to measure the size of the droplets in 14 incremental ranges from 1 μm to greater than 450 μm[15,16]. The hot-wire probe was mounted a sufficient distance from the impinger to avoid aerodynamic interference with it or the pitot tube used to measure the gas velocity.

Results

Data obtained from the first series of tests, as described above, of the total mass concentration measured for various experimental conditions are shown in Figure 5 for a low dust feed rate to the tunnel, and in Figure 6 for a high dust feed rate. It was also determined during the course of sample collection that larger, agglomerated particles which could not settle out of the gas stream in the tunnel due to the high velocity were being collected in the first bend of the sample probe. For this reason, Figures 5 and 6 also show a second value, where available, for the total amount of particulate matter caught by the sample train less the larger particles collected in the probe.

Conclusions

From the data presented in Figures 5 and 6, it can be seen that a significant reduction in dust concentration can be achieved with the SCFT, but that it does not currently meet the 90% target efficiency. It can also be determined that the fog droplets must have a high charge-to-mass ratio for effective control of fine particulate and, as would be expected, that uncharged fog or fog with little electrostatic charge does not provide nearly as good results.

Based upon these conclusions, it was decided that certain modifications to the design of the fogger or to the operation of the wind tunnel were necessary to determine the optimal effectiveness of the SCFT under controlled conditions in relation to the target results. For this reason, the velocity of the gas moving through the tunnel was reduced to allow the larger particles to settle out and to increase the particle/droplet contact time. It was also determined that major design changes to the ionizer would be necessary to increase the charge-to-mass ratio.

A second prototype of the SCFT is currently being fabricated which will be tested in the wind tunnel at University of Arizona in the near future. The modified version will include a completely redesigned atomizer to provide more effective spray pattern. It also incorporates a new method for charging the droplets which preliminary data show to be markedly more effective. It is anticipated that the modified SCFT will easily meet the required target efficiency during the upcoming tests.

Metric Conversion Factors for non-metric units used in text:

1 foot = 0.3048 m
1 dscf/min = 0.0283 dscm/min
1 scfm = 0.0283 scm/min
1 gr/dscf = 2.2883 gm/dscm

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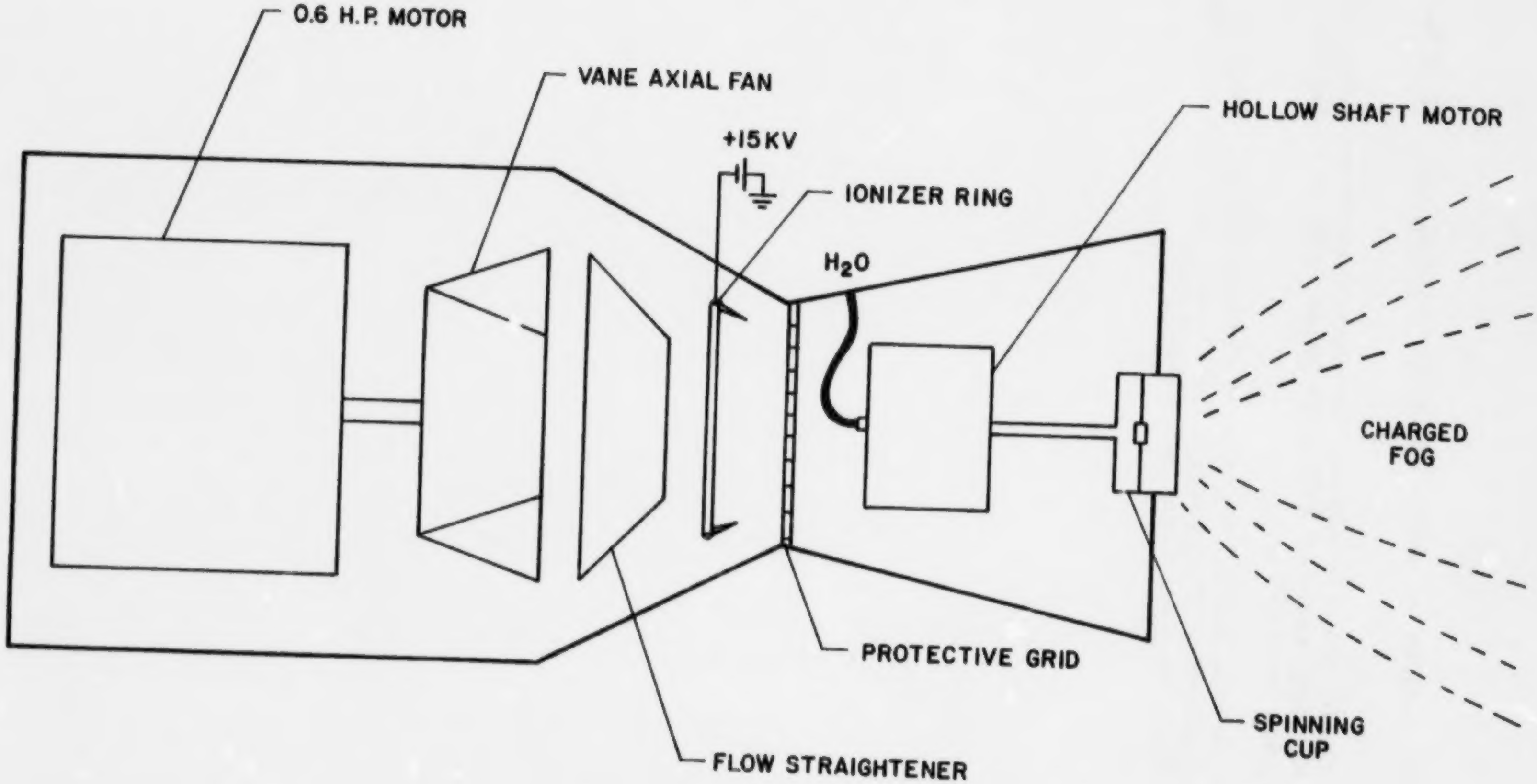

0.6 H.P. MOTOR
VANE AXIAL FAN
+15KV
IONIZER RING
H_2O
HOLLOW SHAFT MOTOR
CHARGED FOG
PROTECTIVE GRID
SPINNING CUP
FLOW STRAIGHTENER

Figure 1. Schematic of spinning cup fog thrower.

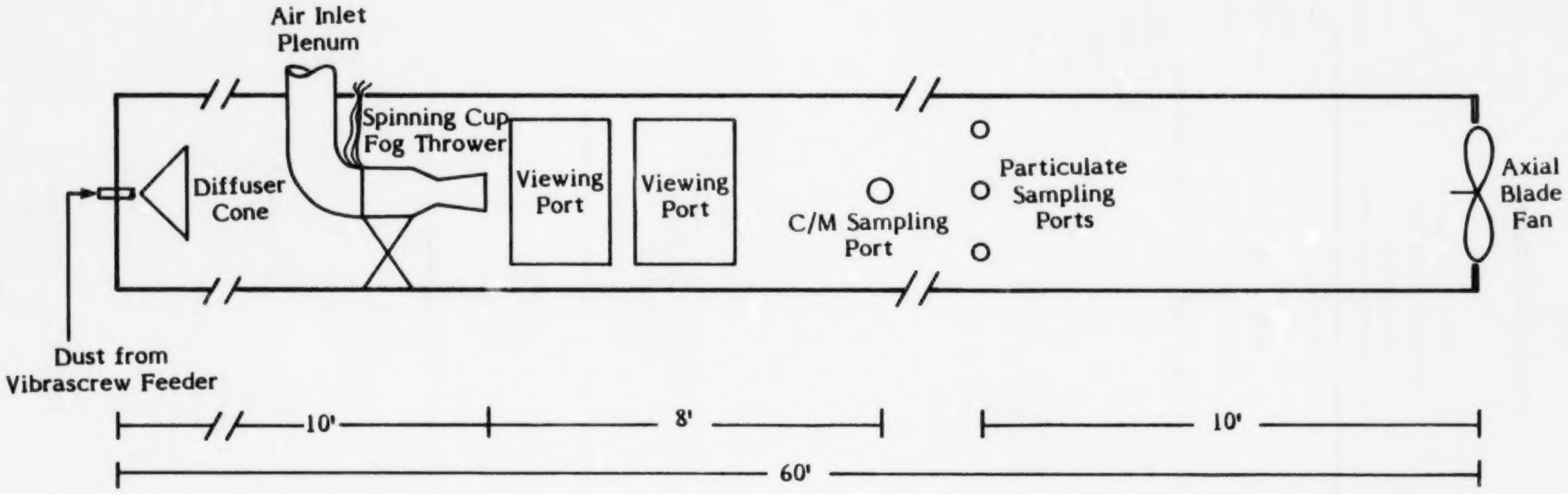
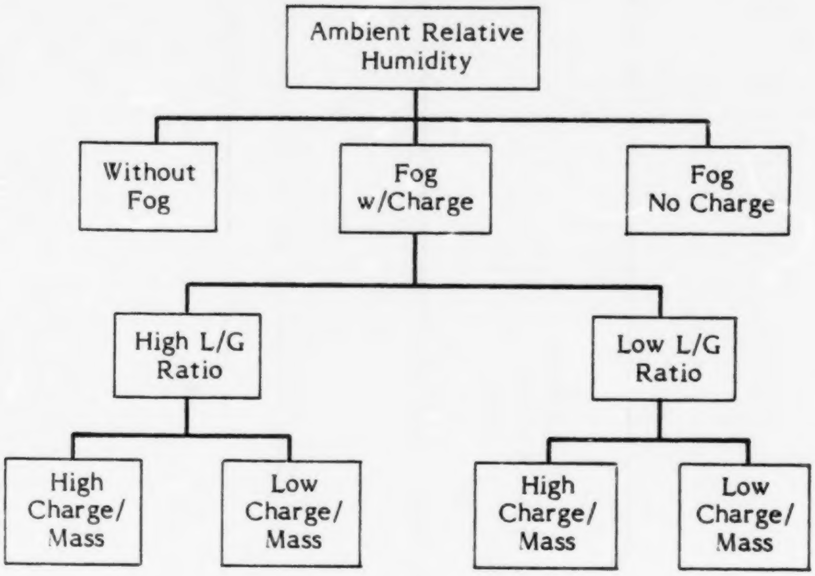

Air Inlet Plenum
Spinning Cup Fog Thrower
Diffuser Cone
Viewing Port
Viewing Port
C/M Sampling Port
Particulate Sampling Ports
Axial Blade Fan
Dust from Vibrascrew Feeder
10'
8'
10'
60'

Figure 2. Schematic of University of Arizona wind tunnel.

(1 foot = 0.3048 meters)

Heavy Dust Loading


Ambient Relative Humidity
Without Fog
Fog w/Charge
Fog No Charge
High L/G Ratio
Low L/G Ratio
High Charge/ Mass
Low Charge/ Mass
High Charge/ Mass
Low Charge/ Mass

Light Dust Loading

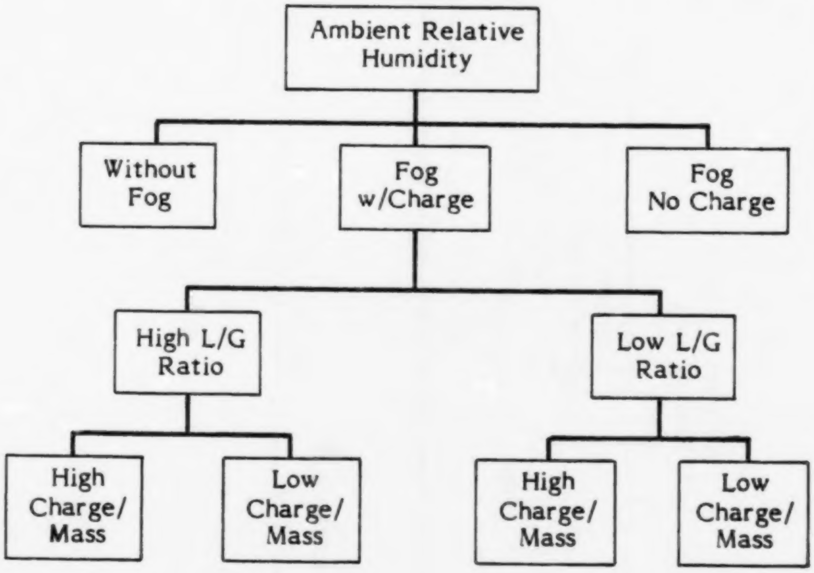

Ambient Relative Humidity
Without Fog
Fog w/Charge
Fog No Charge
High L/G Ratio
Low L/G Ratio
High Charge/ Mass
Low Charge/ Mass
High Charge/ Mass
Low Charge/ Mass

Figure 3. Test plan.

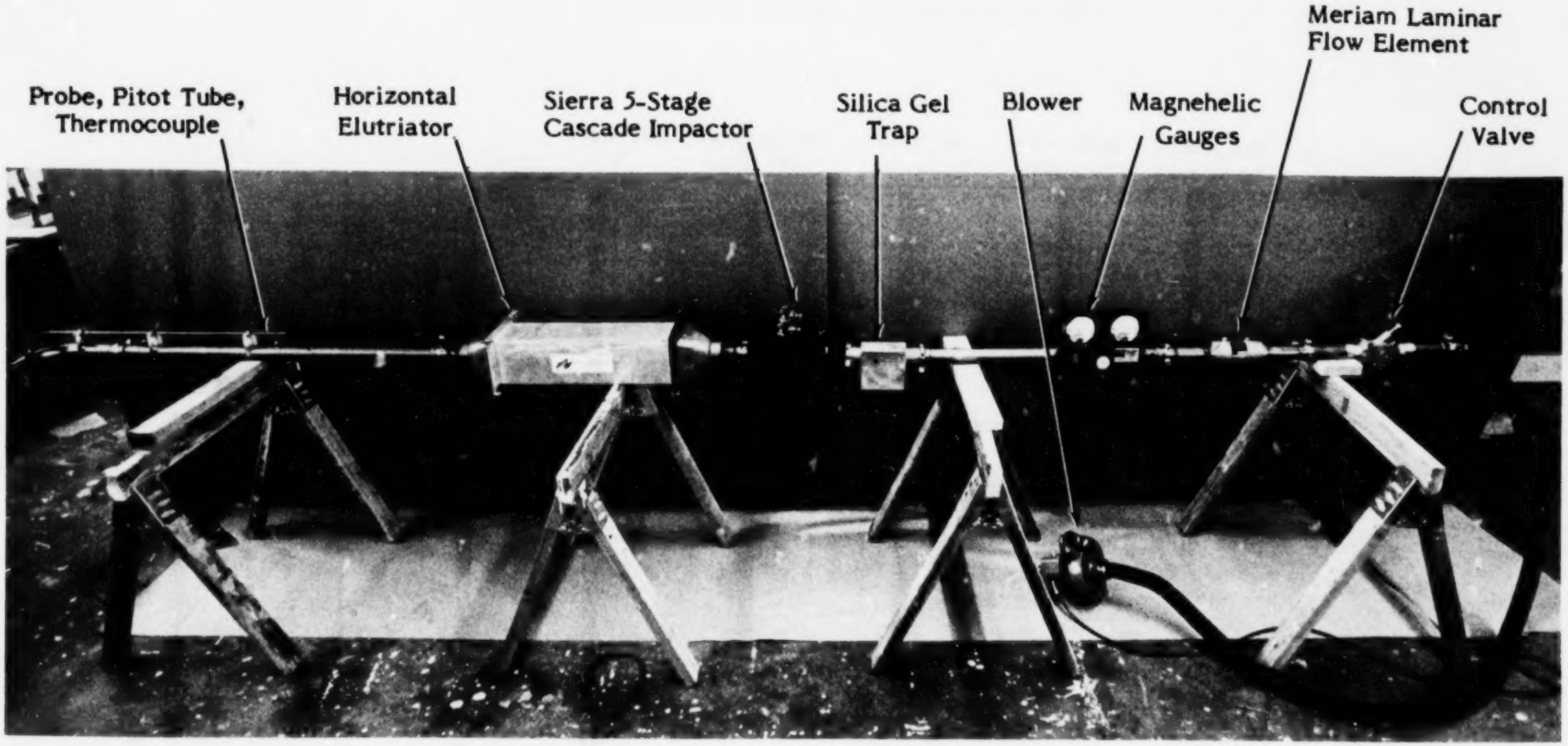

Probe, Pitot Tube, Thermocouple
Horizontal Elutriator
Sierra 5-Stage Cascade Impactor
Silica Gel Trap
Blower
Magnehelic Gauges
Meriam Laminar Flow Element
Control Valve

Figure 4. Particulate sampling train.

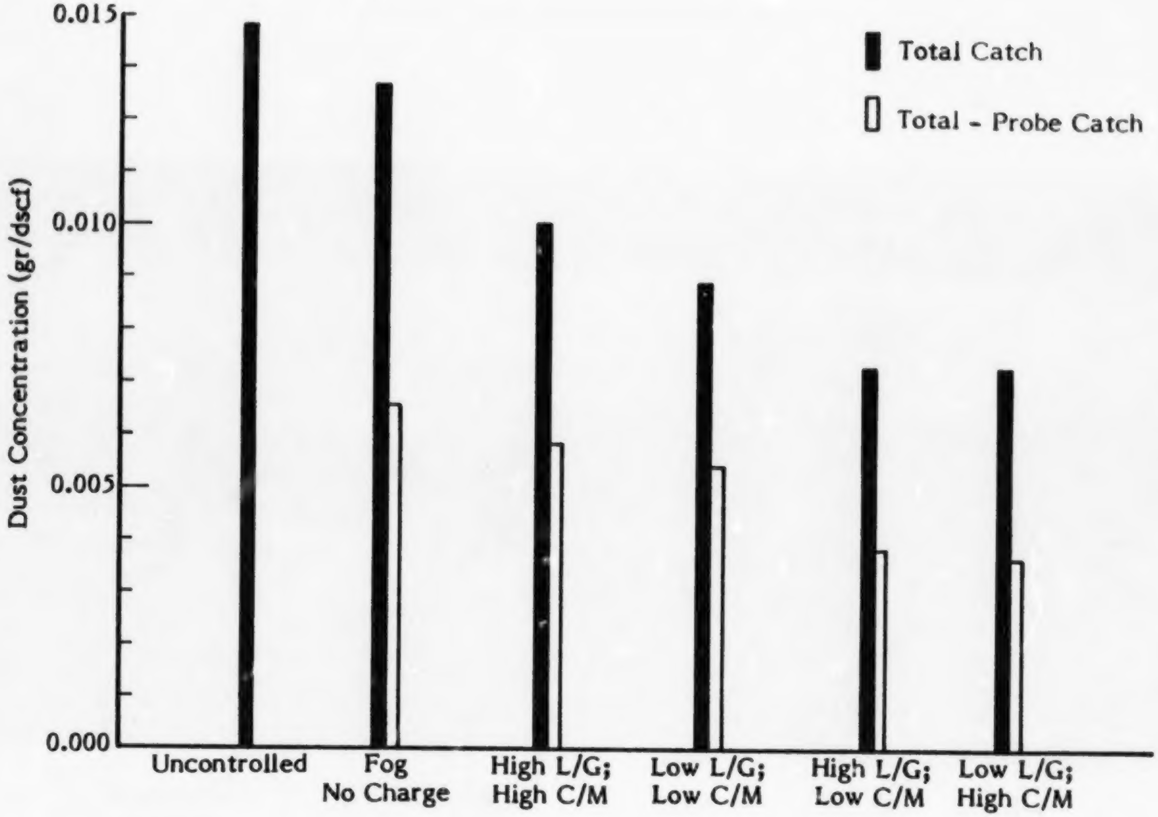


Figure 5. Summary of test data -- light dust loading.
(1 gr/dscf = 2.2883 gm/dscm)

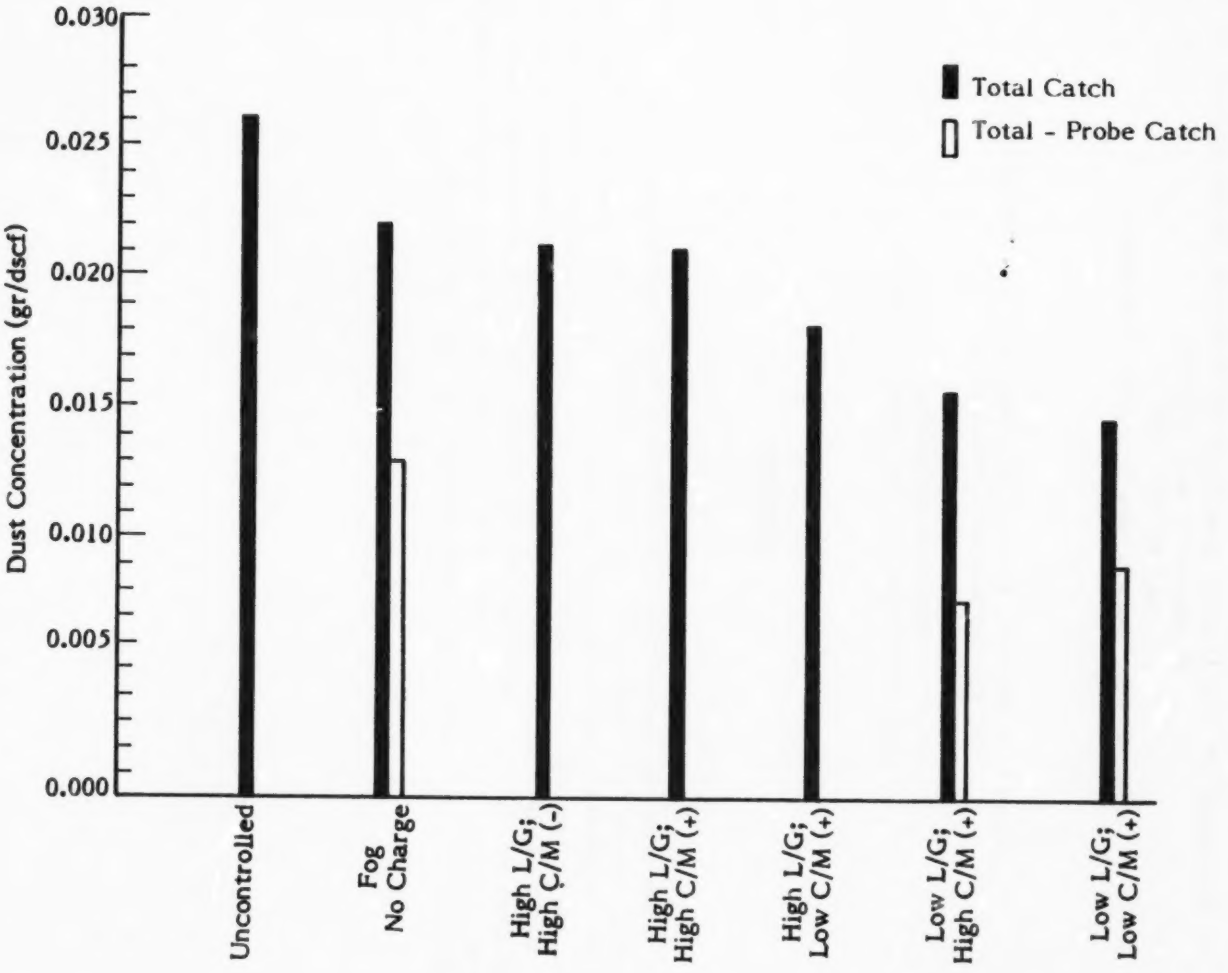


Figure 6. Summary of test data -- heavy dust loading.
(1 gr/dscf = 2.2883 gm/dscm)

CONTROL METHODS FOR FUGITIVE AREA SOURCES

Presented at the Fourth Symposium on Fugitive Emissions:
Measurement and Control
May 28-30, 1980
Monteleone Hotel, New Orleans, Louisiana

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Dr. Dennis Drehmel
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ABSTRACT

The prime control techniques for fugitive area sources are water sprays, enclosures, wind screens and chemical stabilizers. A review of the literature indicated that while cost data was readily available for these methods, estimates of their efficiencies were not supportable from the given data. Nonetheless, future work on wind screens and chemical stabilizers appears warranted. An ongoing field study of a wind screen made of a synthetic material indicates that efficiencies of over 60 percent should be obtainable at a reasonable cost when applied to storage piles.

1.0 INTRODUCTION

Due to the increased regulatory emphasis on fugitive emissions, interest in the type and efficiency of controls applicable to sources generating these emissions has been steadily growing. Prime among the sources of concern are area sources, not only because of the magnitude of their emissions but also since they are not amenable to types of controls with which environmental engineers are most familiar. Furthermore, data on these types of controls are scarce and scattered throughout the literature and, to date, there has not been an attempt to compare the various control options on a cost effectiveness basis to achieve a priority ranking for control strategy development.

In order to rectify this situation the Particulate Technology Branch of EPA's Industrial Environmental Research Laboratory (at Research Triangle Park) is sponsoring a program being conducted by TRC-Environmental Consultants. The purpose of the program is two-fold: first, a review of the literature with respect to fugitive controls applicable to storage piles, unpaved parking lots, and disturbed soil surfaces associated with construction activities; and second, presently ongoing, laboratory studies on the more promising of the identified controls, hopefully pointing the way to future research.

This paper presents the results of the completed Phase I effort and discusses some of the preliminary findings of the Phase II projects.

2.0 PHASE I - LITERATURE REVIEW

2.1 Techniques Identified

Methods, identified from a literature search as prime control techniques for fugitive emissions from area sources, were:

- o Water Sprays.
- o Chemical Stabilizers.
- o Enclosures.
- o Windscreens.

Other control methods (e.g., tailings ponds, vegetative stabilizers, and housekeeping procedures) are not used as extensively as the four cited above and are not dealt with in this paper although they will be covered in the final report to EPA. Brief descriptions of the prime control methods are given below.

2.2 Water Sprays

It was found that, while a number of chemicals have been used to reduce emissions from aggregate storage piles and haul roads, plain water is still the prime wetting agent used. Water use is attractive due to its relatively low cost and ease of application. Effectiveness varies with amount applied, the frequency of application, and meteorological parameters which have a direct bearing on the evaporation rate of moisture. From the latter point it can be inferred that the spray action itself is not an aspect of the control; rather, the use of water to increase the apparent density of the dust is the control mechanism. Sprays are effective only for very large particles at the droplet sizes produced by most commercial spraying equipment. Costs vary with the method of application (e.g., trucks, spray bars) and the amount applied. For large storage piles, the cost of the equipment alone can be high: large watering trucks cost about $250,000. Large coal fields which require continuous watering also have high labor costs associated with this method of control. The direct labor cost of watering one 50 acre coal field can exceed $100,000 per year.

From the literature, a reasonable estimate of the accuracy of this technique can not be made due to the conflicting and inaccurate data found. This point is discussed later.

Disadvantages to using water as a control for area sources are the necessity of having an adequate water supply available, the need for frequent reapplication, and the contribution to the leachate amount.

2.3 Chemical Stabilizers

Three basic chemical stabilizing agents are used, each operating to different principles: wetting agents, hydroscopic salts, and surface crusting agents.

Wetting agents have been used to increase the effectiveness of water and some of the chemical stabilizing agents by reducing surface tension and thereby enabling the water (or chemicals) to be spread more evenly and over a greater surface area then before. Disadvantages are the same as those for water alone, with the addition of the leaching of the chemical into the groundwater aquifer or water treatment system dealing with pile runoff.

Hydroscopic salts, by attracting the water out of the air, increase the surficial moisture content of the dust, increasing its apparent density and thereby reducing its emissions. The prime disadvantage to the use of such materials is the fact that they are water soluble and can therefore be easily washed away. A second disadvantage is that the salts (e.g., $CaCl_2$) are corrosive and may not be able to be used in all instances.

Surface crusting agents, third type of chemical stabilizers, can be composed of various compounds; e.g., styrene/butadiene latices, acrylic latices, vinyl compounds, synthetic polymers, lignosulfonates, and petroleum-based resins. These chemicals are applied wet and when dry form a hard crust on the surface of the material being treated. Costs for these chemicals, even for similar types, vary widely (see Table 1). Latex compounds can be combined with slack wax and filler materials (such as coal dust) which, when applied at elevated temperatures, form a waterproof covering of the pile. Costs for applying this material are reasonable (see in Table 2 for various sized piles). Comparable costs for operations such as compaction and latex crusting are shown in Table 3. The direct savings referred to occur from a reduction in the oxidation and water uptake of coal and are on a yearly basis. Total benefits are based on reductions in the cost of treating the leachate and runoff of the pile, the elimination of the need to monitor the pile's temperature, and other related functions. Cost benefits of hot melt coatings apply only to degradable products such as coal where waterproofing the pile yields these types of results. While these compounds have never been tested for effectiveness it is reasonable to assume that initial efficiencies approach 100 percent. The effective "life" of these materials has not been documented.

2.4 Enclosures

Total enclosures should, by definition, eliminate wind-caused fugitive emissions since the wind would no longer come into direct contact with the source. However, emissions still occur since ventilation of the enclosure is necessary to remove the dust induced by material transfer operations. These emissions are subject to normal stationary source control techniques, however, and are effectively controlled. The cost of this method can be extremely high and varies according to the size and type of structure, associated conveying equipment, etc. Of course, small piles (e.g., sand used by road crews) are effectively and inexpensively controlled by weighted-down tarpaulins.

2.5 Windscreen

Windscreens are porous windbreaks which reduce the velocity of the air behind them. Figure 1 illustrates the performance of a screen having a porosity of 50 percent. Solid (zero porosity) fences are not used as wind-

TABLE 1

CHEMICAL STABILIZER COSTS

Styrene/Butadiene Latices	\$25 to \$50/10^3 Meter^2
Acrylic Latices	\$50 to \$160/10^3 Meter^2
Vinyl Compounds	\$12 to \$50/10^3 Meter^2
Synthetic Polymerts	\$150 to \$420/10^3 Meter
Lignosulfonates	\$25 to \$50/10^3 Meter

TABLE 2

HOT MELT COATING COSTS

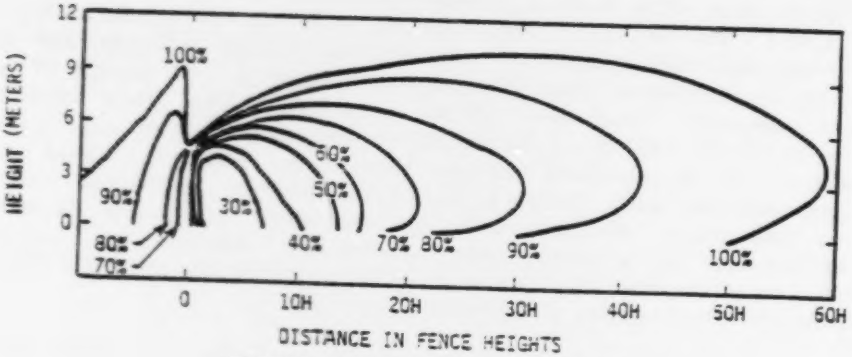
Pile Size Metric Tons	Surface Area Meters	Cost to Treat, \$	Cost \$/Metric Ton
45,360	6,782	2,623	0.058
90,720	13,006	5,137	0.057
226,800	32,515	12,788	0.057
453,600	65,030	25,466	0.057
680,400	97,545	38,255	0.057

TABLE 3

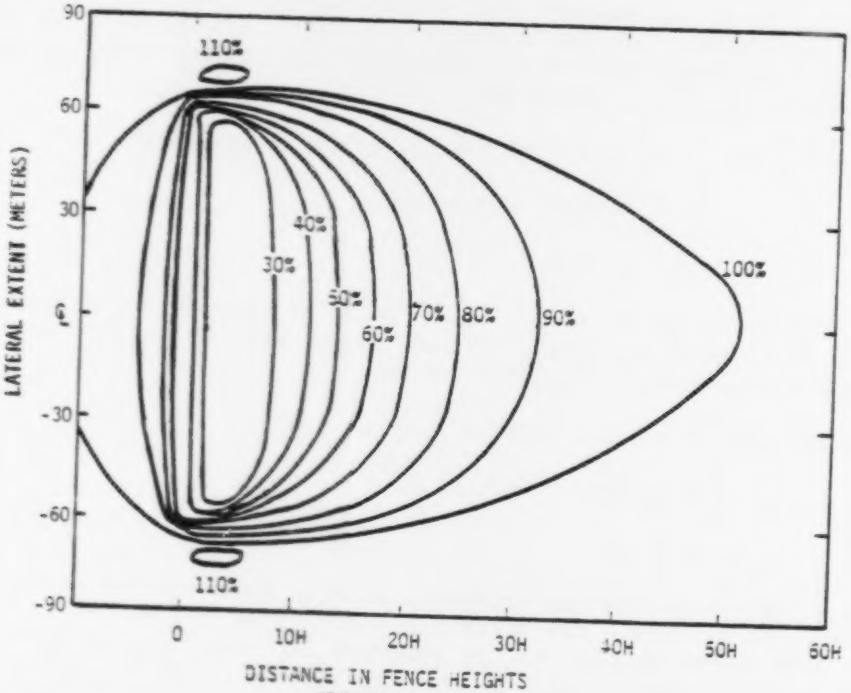
COST SUMMARY FOR MATERIALS APPLIED TO COAL PILES*

Treatment	Cost to Treat \$/Metric Ton	Direct Savings \$/Metric Ton	Total Benefits--Value Equivalent \$/Metric Ton
Compaction	0.088	0.303	0.89
Latex Crust	0.126	0.716	1.20
Hot-Melt Coating	0.144	1.15	2.09

* Assuming a coal pile of 250,000 metric tons at \$20 per metric ton



VERTICAL SECTION (ALONG ℄ OF FENCE)



GROUND PLAN

FIGURE 1: WIND VELOCITY PATTERNS

4008-001

breaks for large sources since the downstream turbulence created by the breaks may actually induce more emissions than those which would have occurred without the breaks. Figure 1 shows that a fugitive emission source placed within 10 fence heights downstream of the fence would have the air speed reduced to 40 percent of its upstream value in the vicinity of the source. (Note that this does not mean that the emissions would be reduced by 60 percent.) The emission reduction depends on the relationship between the air speed and the amount of particulate matter emitted and has been estimated to be anywhere from a straightforward $E\ \ V^1$ to $E\ \ V^9$ and just about every exponent in between. Also, note that, for every type of dust, there is a critical threshold velocity at and below which only an insignificant amount of particulate matter would be removed. This threshold velocity depends on such factors as particle size, adhesive forces particular to the dust, surface moisture content, and bulk density. The overall efficiency of a windscreen, therefore, depends on the threshold velocity of the dust, the relationship between emission and velocity and, of course, local meteorological parameters.

For example, suppose that 50 percent of the time the wind at a given location comes from a 30° sector and that a storage pile can be shielded from its effect by a semicircular fence. Air velocity readings from the noted direction can be broken down as: - 10 percent of the time, less than 10 kilometers per hour; 60 percent of the time, 10-20 kilometers per hour: 20 percent, 20-30 kilometers per hour and 10 percent, averaging 40 kilometers per hour. If the threshold velocity of the dust is about 10 kilo- meters per hour and if the emissions are proportional to kv^3 then, before control, emissions can be described as:

$$\text{Emission rate} = k\ (0.6)\ 20^3 + ka(0.2)(30)^3 + k(0.1)(40)^3$$

$$= k\ (4800 + 5400 + 6400)$$

$$= k\ 16{,}600$$

when the highest value of the velocity range is used as the average. After installing the fence, only the last two ranges will be beyond the threshold and the emission would be characterized as:

$$\text{Emission rate} = k\ (0.2)\ (15)^3 + k\ (0.1)\ (20)^3$$

$$= k\ (675 + 800)$$

$$= k\ 1475$$

There is a reduction over the uncontrolled wind from the one sector of about 91 percent. To determine the overall efficiency of the fence, the emissions from the unshielded section of the piles would also have to be determined. If these emissions were about 30 percent of the total (k 7115), then the overall efficiency of the fence would be about 64 percent. Naturally, the closer the fence is to the pile, and the more unidirectional the wind is, then the greater is the efficiency that can be achieved.

Windscreens can be made of various materials and can be arranged in various configurations. Materials of construction include structural steel, wooden slats in a cyclone fence, and a synthetic material of the type used for glare screens and snow fences. Cost varies with material, design, and height. A movable 4 meter high fence could cost about $3,280 per linear meter if made of structural steel to enable it to be picked up and moved by forklifts. A 25 meter high permanent screen could cost the same, if made of snow fence material.

3.0 COST-EFFECTIVENESS FACTOR

The prime end result of the Phase I literature review was to have been the development of a cost-effectiveness factor for each control method identified.

In general, although cost data were relatively easy to obtain from the literature, chemical manufacturers, etc., efficiency data were, for all practicable purposes, non-existent. This is understandable for a number of reasons. There are just not that many reports containing hard data on control efficiency for fugitive sources. At the beginning of the study, a computerized search of APTIC, NTIS, Engineering Index, and Pollution Abstracts yielded fewer than 200 potential sources of information. Most of the publications examined did not contain usable data. Many articles were oriented toward control of fugitive dust in order to reduce nuisance complaints. Typically these reports described the use of a type of control, housekeeping procedure, or combination thereof which reduced the incidence of the complaints. While these studies were useful in showing the state-of-the-art control, actual data test were, for the most part, not given or available. In the relatively few instances where control efficiency data were obtained or noted in the publication, they did not meet the preset criteria for acceptance. These criteria were:

- Tests had to be performed upon the sources using acceptable methodology and instrumentation.
- Judgements on the effectiveness of a control under different conditions than those tested were not permitted unless strong evidence of a trend was noted and a basis in theory established for the phenomeon.
- Test data and conclusions were to be considered absolutely valid only for the source tested. Extension to similar sources required that those factors affecting particle transport be quantified during the tests and that data on these factors be available for the similar sources. For example, particle size estimates would have to have been made for the pile tested and data available indicating that the size is similar for similar sources. It was not considered necessary that particle size data be available on the similar sources (although this would have been the ideal situation); rather, engineering judgement could be used to infer that the size was the same.
- Data from tests performed on one type of source could not be extended to dissimilar sources (e.g., test results on sand and gravel operations could not be applied to coal piles) without extensive supportive evidence.

- Wind tunnel testing could only be used when compared with field results or where various control options were tested under similar conditions.

Applying these criteria to the publications found eliminated, for all practical purposes, all of the data from consideration. This should not have been a surprise for a number of reasons. As noted before, available data are not extensive. Most efficiencies of available data are derived, rather than calculated directly. Also, to confuse the issue somewhat, some numbers quoted in the literature appeared to increase each time they were referenced. As an example of how this can occur, one reference stated:

> "A study on the effect of watering on construction sites indicates that extensive wetting of the soil may reduce emissions from existing construction operations up to 60 or 70 percent. The study suggested that wetting of access roads twice a day with an application of .5 gal. of water per square yard will suppress dust emissions from existing baseline construction practices by 50 percent."

The study cited actually stated:

> "Watering on construction sites produced a wide variation in apparent control efficiencies, due in part to the highly variable nature of the emission sources. Activity logs kept at the construction sites showed that some sampling periods with extensive watering were accompanied by hi-vol readings 60 to 70 percent lower than anticipated with no watering, while on other days the apparent effect of the watering was negligible. The same variations were noted in analyzing data from sampling periods with rainfall. With daily watering and complete coverage, average control efficiency is about thirty percent. This value is partially verified by another study indicating a 30 percent reduction in dust emissions over continuously traveled gravel and dirt roads on days when their surface was moist. However, with watering twice a day at the same application rate, a reduction of 50 percent appears feasible."

As can be seen, these studies did not establish the effect of watering, but rather, extrapolated extremely limited data to produce undependable results.

In conclusion, evaluation of the literature indicated that there is virtually no accurate or usable data relating to control efficiency for fugitive area sources and that, as a result, this data must be generated.

4.0 PHASE II PROGRAMS

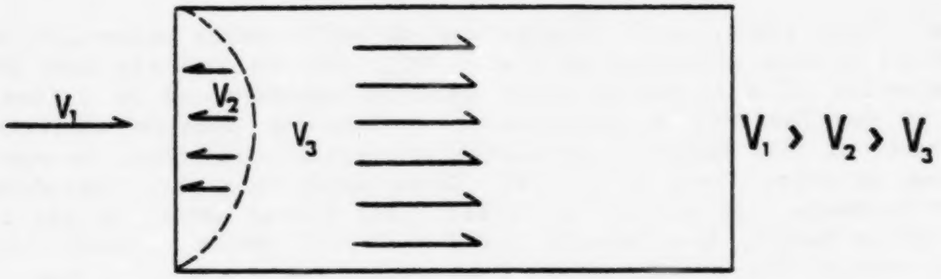
The Phase I results indicated that the present state of knowledge with respect to fugitive emission generation and transport is not extensive. Available information on control technique effectiveness is practically nonexistent. To alleviate this situation somewhat, Phase II was oriented toward a better understanding of the transport phenomena and a first-cut approach to quantifying the effectiveness of the two most promising techniques, chemical stabilizers and windscreens. While Phase II is still ongoing, some partial results are encouraging and are presented here for review.

4.1 Particle Transport

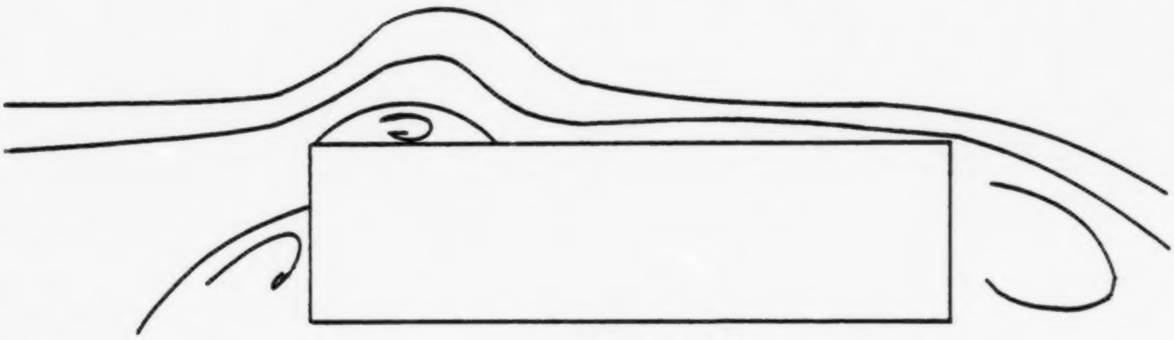
While much has been established on a theoretical basis describing the behavior of particle transport, agreement between theory and field results has been poor. Part of the difficulty lies in the oversimplification of the approach in field studies undertaken to date. For example, only recently has surficial moisture content and the size distribution of the dust available for transport been measured during tests at storage piles. Attempting to force-fit data to a given transport model has resulted in simplistic equations good only for the pile on which the data were taken. To resolve this, a wind tunnel study is being performed to quantify the effects of pile shape, moisture content, particle size, and turbulence intensity on the quantity of emissions generated. To date, only the results on pile shape are available. These data indicate that the oncoming wind is accelerated up the slope of the pile such that the air speed at the top of the pile is increased about 50 percent over ground air speed. The amount of the increase depends somewhat on slope. Slopes with leading angles equal to about 10° produce less than half the increase in velocity at the top of the pile than slopes with angles greater than 20°. The high velocities at the top of the pile induce flow patterns as shown in Figure 2. While this schematic is for a block, the same phenomenon holds true for a pile with a sloping edge. Therefore, in predicting the emissions from a pile, the air speed used in a predictive equation may not be amenable to a single value; rather, emissions from different sections of the pile can be referenced to the approach ground speed only if different equations are used for each section. Ongoing work in TRC's wind tunnel will be used to obtain the form of these equations so that future field studies can use them to set up their testing programs and evaluate their results.

4.2 Windscreen Studies

One of the more promising control alternatives identified in the literature was windscreens. A major drawback to their use, however, is the materials of construction; usually, wood slats in a cyclone fence or snow fence type materials are used. While such materials are acceptable for fences of limited height, protecting large piles could require fences of 15 meters or more in height. Long stretches of haul roads, while probably not


V_1
V_2
V_3
$V_1 > V_2 > V_3$

TOP VIEW



SIDE VIEW

FIGURE 2: FLOW PATTERNS ACROSS A BLOCK PILE

needing a high fence, would require one of sufficiently reasonable cost to be applied to long stretches of road. TRC's ongoing investigation includes an evaluation of a synthetic fence material manufactured by Julius Koch, Inc., of New Bedford, Massachusetts. Preliminary results indicate that performance of this material, available in varying porosities, is equivalent to those of other fence materials. Since material costs, including connecting hardware, are approximately $19.7 per linear meter for the 1 meter wide section tested, this material is a preferred option in most instances. Ongoing studies are being performed to evaluate the use of a semicircular and a circular fence.

5.0 CONCLUSIONS

An evaluation of the available literature indicated that stated efficiencies for the prime control techniques applicable to fugitive area sources were based on unreliable data of limited quantity. For this reason, future testing must be directed toward developing this data. Ongoing wind tunnel studies at TRC indicate that emissions from a storage pile depends on pile configuration and that seperate equations for different pile sections may have to be developed to accommodate this phenomenon.

Full-scale field testing of a synthetic fiber windscreen indicates that the screen performs equivalently to other materials and that, due to its cost, this material is preferable to others. Ongoing programs are evaluating semicircular and circular screens.

CIVIL ENGINEERING FABRICS APPLIED TO FUGITIVE DUST CONTROL PROBLEMS

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ABSTRACT

Fugitive dust sources contribute substantially to both total suspended particulate (TSP) and inhalable particulate. Emission rates from unpaved roads, construction activity, and other area sources have been estimated at 320 x 10^6, 27 x 10^6, and 4 x 10^6 tons*/year, respectively. This may be compared to 14 x 10^6 tons/year, the emission rate for all point sources. Within a given industry, the contribution of fugitive emissions can be more than 50% with the added problem that these particles may contain toxic or hazardous substances.

Civil engineering fabrics are in common use for a number of purposes including: 1) ground stabilization; 2) subsurface drainage; 3) railroad construction and maintenance; 4) sediment control; and 5) erosion control. Fabrics are available from Celanese, DuPont, Monsanto, and Philips Fibers under the trade names of Typar, Bidim, Supac, and Mirafi. Use of these fabrics for air pollution control is a recent development and the subject of recent and future field tests.

Reduction of emissions from unpaved roads is achieved by covering the road first with the fabric and then with coarse aggregate. Unpaved parking lots, inactive piles, and construction sites could be controlled in the same way. During tests in November 1979 on an unpaved road constructed with Bidim, the average reduction in TSP was 58% and in inhalable particle concentrations was 46%. More tests are planned at both eastern and western sites in the spring of 1980 and a year-long monitoring at a western site will begin in the summer of 1980.

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*To convert tons to kilograms, multiply by 907.

INTRODUCTION

In the arid regions of the western United States, local sources of fugitive dust appear to be the most significant contributors to ambient levels of total suspended particulate (TSP). These sources also contribute to the inhalable fraction although to a lesser degree. Vehicles travelling on unpaved roads are a major portion of these emissions, ranging from 54% of the total annual TSP emissions in Phoenix[1] to 9% in Denver and 48% in Colorado Springs.[2] An integral part of a particulate control plan is identifying fugitive emission control measures for unpaved roads. In addition to unpaved roads, construction sites, haul roads, and open areas within industrial sites are important contributors to TSP and may be sources of undesirable species such as lead.

Traditional control techniques to reduce unpaved road emissions, such as paving, chemical stabilizers, watering, graveling, and traffic controls, have been analyzed in several studies.[3,4,5,6,7,8] However, the use of a civil engineering fabric medium underlying the aggregate roadbed is a promising new technique which, after further study, may have application as an alternative control strategy in the western United States. It may, in addition, have other benefits such as reduced road maintenance. Fabric under aggregate may also be used to control unpaved parking lots, construction sites, and disturbed open areas. For these reasons, The Environmental Protection Agency (EPA) Regional Office in Denver is assisting EPA's Industrial Environmental Research Laboratory at Research Triangle Park in North Carolina in planning a study of the effectiveness of this type of road treatment on an unpaved road segment on the Ft. Carson Army Base near Colorado Springs, Colorado. This paper describes the use of civil engineering fabrics and their role in the context of the EPA particulate control program.

BACKGROUND

Even with the application of Reasonably Available Control Technology (RACT) on all stationary sources, many TSP nonattainment areas are projected to exceed the NAAQS after the Clean Air Act's 1982 deadline. Control of the remaining nontraditional sources has presented a formidable planning task to those responsible for State Implementation Plans (SIP's). The problem has been complicated by the lack of definitive information on the cost-effectiveness of the various control measures and the likelihood that a new inhalable particulate standard is in the offing. Few States or local governments are prepared to commit large amounts of public funds to projects of uncertain value in achieving the new inhalable particulate standards. The Colorado Air Quality Control Commission, in fact, has stated in policy paper 78-1 that it is not reasonable to gear a control program to meet a questionable standard and that it is the policy of the Commission to direct control efforts at the respirable fraction.

The EPA Administrator recognized these problems in his February 24, 1978, guidance on SIP's for nonattainment areas. This guidance states that after RACT for traditional sources, States could conduct demonstration projects and studies in lieu of adopted specific measures as long as the data on costs and benefits could be analyzed and strategies adopted and implemented in time to meet the 1982 deadline.

As SIP's were submitted in the months following January 1, 1979, it became apparent that most states had opted for the demonstration project alternative, although a few areas, such as Phoenix and Colorado Springs, committed to extensive paving programs, which have since been delayed.

As a result EPA has provided further guidance on what should be the emphasis areas in 1980 while the standards review is in progress. The first priority is to assure that RACT is applied to all traditional sources. The second is for those areas which have not yet done so to complete a problem assessment of sources, emission, and nature of particulate (size distribution in particular). EPA will be supporting several major studies of available control measures to determine source/receptor relationships, effectiveness, and air quality impacts.

EPA's Denver Regional Office has supported many such studies which may eventually lead to widespread implementation. Through a grant to the State of Colorado, a study design is now being developed to conduct an evaluation of alternative snow control practices. The demonstration study of civil engineering fabric in unpaved roads fits in well with EPA guidance by providing an ideal opportunity to evaluate promising new technology.

FABRIC DESCRIPTION

At least four major manufacturers of civil engineering fabrics market in the United States. These companies are Celanese, duPont, Monsanto, and Philips Fibers. A description of some of their products is shown in Table 1. Most manufacturers offer a range of properties according to thickness. Data in Table 1 should be interpreted as showing that generally the same range of properties is covered by all manufacturers. Usually civil engineering fabrics are sold for road stabilization, support, drainage, erosion control or reinforcement. Such fabrics have been used under railroad tracks, rip-rap, and paved and unpaved roads. Fabrics are available in strengths to take loads from haul trucks and railroad trains, are rot resistant, and have been estimated to have a useful lifetime of 12 years. The approximate 1980 cost is $1.00 per square yard.

FIELD TEST SITE DESCRIPTION

The test section is a 610 meter (2,000 foot) segment of unpaved road located at the northern boundary of the Ft. Carson military installation south of Colorado Springs, Colorado. There were several reasons for the selection of Ft. Carson as the site. First, Ft. Carson officials were interested in cooperating in such an experiment. As a training center for ground-based artillery, the base contains long stretches of unpaved roads and cleared areas which are subject to fugitive dust emissions. For sometime Ft. Carson has been considering conducting experiments with various dust palliatives to reduce these emissions. Ft. Carson officials were most cooperative in assisting in site selection, providing monitoring equipment, and installing the fabric itself. In addition, the fabric

Table 1. PROPERTIES OF CIVIL ENGINEERING FABRICS

	Brand Name			
	Bidim	Mirafi	Supac	Typar
Composition	polyester	polypropylene	polypropylene	polypropylene
Structure	spunbonded	woven	heat bonded	spunbonded
Thickness, mils	60-190	25	50	15
Weight, oz/yd^2	---	4	5.3 (up to 16)	4
Grab Strength, lb	115-610	200	150 (cross direction)	130
Burst Strength, psi	225-850	325	300	---
Water Permeability, cm/sec	0.03	---	0.05	---

To convert to metric equivalents

Multiply	by	to convert to
mils	0.00254	cm
oz/yd^2	25.9	g/m^2
lb	453.6	gram
psi	703.1	kg/m^2

had not yet been tested at a western site.

The road extends in an approximate north-south direction and provides access to several residential areas on the post. It is not in the training area, but is used mainly by Army personnel in light-duty vehicles enroute from or to these residences. An occasional track vehicle uses the road as well. Open fields extending for 100 meters or more lie on both sides of the road. The test section slopes gently upward toward the south end. The majority of the traffic traverses the entire length of the segment, but an occasional vehicle either enters or exits at two infrequently used intersections.

In November 1979, a Monsanto fabric was installed in the southernmost 305 meter (1,000 foot) section by Ft. Carson construction crews under Monsanto supervision. The northern section is being used as a control section.

TEST RESULTS

Field tests of ambient particulate concentrations around the test road were conducted in November 1979 and April 1980. The test apparatus consisted of upwind and downwind stations equipped with Hi-Vols and dichotomous samplers in November and Hi-Vols and size selective Hi-Vols in April. The data derived from the Hi-Vol measurements are shown in Table 2. The lower increase in ambient concentration downwind of the fabric-plus-aggregate road is shown by comparison to the increase across the control section. The fabric-plus-aggregate road gave an average of 47% lower emissions within a range of 30 to 70% lower emissions. Wind speeds during November were lower than during April which corresponded to greater emissions reductions during November than during April.

Data for the control of inhalable particles (those with diameters less than 15 micrometers) are shown in Table 3. As noted above, the November data was derived from dichotomous sampler measurements and the April data from size selective Hi-Vol measurements. The percentage reduction shown in the table is again the lower increase in emissions from the fabric/aggregate road as compared to the control road. The reduction averaged 43% within a range of 26 to 53%. Again the reduction was slightly greater with lower wind speeds.

These results may be used to compare the cost effectiveness of civil engineering fabrics for unpaved road control to other methods as shown in Table 4. Based on cost estimates by Cooper[9] and Blackwood,[10] the other methods have a cost of at least $220 to $300 for each kilometer of road per year per % reduction in emissions. For fabric/aggregate roads, the cost is $140 per km/yr/% reduction. Thus, the fabric/aggregate road is more cost-effective and avoids the problem of availability of water in arid regions for watering or that of oil runoff for oiling.

FUTURE MONITORING PLAN

The current plan calls for a 1-year study to collect data on the following parameters: total suspended particulate, size fraction under 15 micrometers, vehicle counts, precipitation, and wind speed/direction.

Table 2. CONTROL EFFICIENCY OF ROAD CARPET (BIDIM) FOR TOTAL SUSPENDED PARTICLES

Date	Wind Speed, mph	% Reduction
11/7/79	0.6	60
11/9/79	2.4	59
11/14/79	0.3	30
11/16/79	0.2	70
4/28/80	7	35
4/28/80	7	44
4/29/80	8	36
4/29/80	9	39
Average		47

To convert mph to cm/sec multiply by 44.7.

Table 3. CONTROL EFFICIENCY OF ROAD CARPET (BIDIM) FOR INHALABLE PARTICLES

Date	Wind Speed, mph	% Reduction
11/7/79	0.6	53
11/9/79	2.4	31
11/13/79	1.5	49
11/16/79	0.2	48
4/28/80	7	45
4/28/80	7	39
4/29/80	8	26
4/29/80	9	49
Average		43

To convert mph to cm/sec multiply by 44.7

Table 4. COSTS OF UNPAVED ROAD CONTROL

Method	Expected Efficiency, %	Cost Estimates, \$/km-yr by Cooper[9]	Cost Estimates, \$/km-yr by Blackwood[10]	Cost Effectiveness \$km-yr-%
Oiling	50-98	up to 180,000	11,000	220-1800
Watering	40	25,000-39,000	11,500	290-1000
$CaCl_2$	60	18,000	---	300
Road Carpet	45	---	6,000	140

Five pairs of Hi-Vols/Hi-Vol with size selective inlets are to be used. Because the predominant winds are drainage winds which are diurnal in nature, from the northwest in the morning and southeast in the afternoon, the monitor pairs are located north of the center point of each test section and should measure mainly upslope afternoon emissions. A background site will be located far enough away so as not to be impacted by road emissions.

Instruments will be maintained and filters weighed by the local health department which conducts the TSP monitoring for the State and is cognizant of EPA quality assurance procedures. Samples will be taken every 6 days to correspond to the sampling schedule for other Hi-Vols in the area. Because of the heavy filter loadings, 4 or 8 hour samples may be taken instead of the normal 24-hour sample.

All data collected will be submitted to the EPA Regional Office for analysis and publication of results.

Data collection should begin in June or July and continue for 1 year. A preliminary report should be available, based on 6 months of data, by April 1981, and a final report should be available late in 1981.

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FUGITIVE PARTICLE EMISSION CONTROL USING SPRAY CHARGING AND TRAPPING SCRUBBER

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Abstract

The control of fugitive process emissions (FPEs) with a Spray Charging and Trapping (SCAT) scrubber was evaluated both theoretically and experimentally. The SCAT system uses an air curtain and/or jets to contain, convey, and divert the FPEs into a charged spray scrubber.

Experiments were performed on an 3.8 m^3/s bench-scale spray scrubber to verify the theory and feasibility of collecting fugitive particles with charged water spray. The effects of charge levels on drops and particles, nozzle type, drop size, gas velocity, and liquid/gas ratio on collection efficiency were determined experimentally. The results of the experiments and the comparison between theory and data are presented.

An air curtain was developed for conveying the FPEs to the spray scrubber, deflecting the crosswind, and containing hot buoyant plume. The design and air flow field for the air curtain are presented.

The SCAT system is also being applied to improve the capability of street sweepers for collecting inhalable particles. Preliminary design approaches are presented.

FUGITIVE PARTICLE EMISSION CONTROL USING SPRAY CHARGING AND TRAPPING SCRUBBER

Introduction

Fugitive emissions constitute a large percentage of total particulate emissions. Therefore, control of fugitive process emissions and fugitive dust will be an essential ingredient in control strategies for particles. EPA classified fugitive emissions into two categories: fugitive dust emissions and fugitive process emissions. Fugitive dust emissions originate from non-industrial activities; e.g., wind blown dust, entrained street dust, agriculture, and construction and demolition. Fugitive process emissions are any non-ducted emissions due to industrial activities such as loading and unloading raw materials, unpaved road in a plant, metal pouring, and material charging.

Fugitive emissions are diffuse and typically come from many small sources as opposed to a single large emitter. Present control methods use secondary hooding at the local source of emissions, total building enclosure and evacuation, or water sprays. Secondary hooding and total building enclosure and evacuation require high energy and capital investments. In addition, secondary hooding may not be efficient in gathering fugitive emissions.

Spraying with water could be effective for some processes and materials which can tolerate water, such as transfer of raw materials on conveyor belts. The main function of the spray in this application is to stabilize the dust to keep it from dispersing. If the dusts are already airborne, spraying with water alone will not do much good. The water drops can catch some particles. However, the drops and collected particles will re-disperse in the air after the water has evaporated.

A much simpler and cheaper method for controlling fugitive process emissions is by diverting the fugitive particle emission (FPE) into a control device located near the source. The particles are then removed for the air and disposed of. The SCAT (Spray Charging and Trapping) scrubber is such a system. It uses air curtains and/or jets to contain, convey, and divert the FPEs into a charged spray scrubber. This control method minimizes the apparatus required to contain, convey, and control the fugitive emissions.

SCAT System

Figure 1 shows an example of the SCAT system. It has two sections. One section contains the air curtain and air push jet assembly. The other section consists of a particle control device. The SCAT system uses water sprays, which could be charged for particle removal.

The two sections are arranged in a push/pull arrangement with the fugitive particle emission source situated between the two sections. The fugitive particles are contained with air curtains and are pushed away from the source into the spray scrubber. The scrubber has a low pressure drop entrainment separator (e.g., zigzag baffles) to remove the spray drops.

The water from the entrainment separator can be passed through a separation process, such as a filter, to remove the collected dust particles. The water may then be recycled and the dust may be disposed of in such a way as to prevent its re-dispersion. Alternatively, a blowdown stream of dirty liquid may be directed to a disposal system.

The major SCAT system feature which suits it to FPE control is the use of air curtains and/or air push jets to contain and convey FPEs. The use of air curtains will minimize the requirement of solid enclosure (hooding). It will be easy to build and unobstrusive. The air curtains could also be used to deflect the wind to minimize the dispersion and the volume of air to be cleaned and be used to contain FPEs from hot sources. For example, the Naoshima Smelter of Mitsubishi Metal Corporation at Naoshima Island uses a system similar to SCAT to control the fugitive emissions from a copper converter (Uchida, et al. 1979). In that system, fumes from the converter are contained and then are ducted to a central particle control device.

A SCAT system could have the following components.

1. Air curtain and/or air push jets,
2. Water sprays (could be charged),
3. Entrainment separator,
4. Fan and pump, and
5. Water treatment.

It is not necessary for a SCAT system to have all the components. There is no one fixed design and configuration. Its design depends on specific sites and applications. Of the above five components, air curtains and water sprays required further study. To generate design information quickly, the air curtain and the spray scrubber were studied individually in separate bench scale devices before being combined into one prototype SCAT unit. The prototype was then used to determine the effect of crosswind, hot source, and particle containment efficiency.

Air Curtain Study

An air curtain is a sheet of air blown either by a jet or out of a slot at high speed. It has been widely used in industrial and commercial plants, mainly to provide constant access or to isolate a warm interior from the cold outdoors or vice versa.

Most of the published information on air curtain performance and design has been related to air conditioning and ventilation. There is little published literature on its dust containment capability even though it has been used for this purpose in industry. Only one report has been published on the application of air curtains to block or deflect crosswinds.

Design of the SCAT system requires information on several parameters of the air curtain jet stream such as the jet expansion angle, air entrainment ratio, mixing of particles in the curtain, effect of crosswind, and the effect of hot sources. The jet expansion angle and particle mixing determine the overall cross-sectional dimensions of the spray scrubber or the receiving hood. The air entrainment ratio determines the volumetric flowrate. The crosswind and heat effect dictate the placement of air curtains and the sprays. These parameters are being studied.

In the SCAT system, the air curtain should have a small expansion angle, small air entrainment ratio, and a uniform velocity distribution. It is generally known that for uniform velocity distribution the distribution manifold or duct should have a constant static pressure from end to end. To obtain constant static pressure, the manifold should have either a very large cross-sectional area compared to the total nozzle area or a decreasing cross-sectional area to keep the velocity head in the manifold constant.

Early attempts to simplify construction of an air curtain manifold by drilling holes along the duct did not yield uniform flow. The main reason was that the duct cross-sectional area was not much larger than the total hole area. A better distribution manifold shown in Figure 2 was built. The manifold was of rectangular cross-section 35.6 cm x 30.5 cm. An adjustable plate was placed in the duct so that the flow area decreased along with duct. Ideally the plate should be curvilinear in shape. But for the short duct used in the present study, about 3 m in length, the plate may be straight. The use of straight plate greatly simplified the construction.

The air jet nozzle was a continuous slot 2.1 m (7 ft) long. The slot was formed by two parallel plates which protrude 22.9 cm (9 in.) from one side of the duct. The distance between the plates, which is the slot width, could be adjusted. The slot was divided by thin cross-plates, 7.6 cm (3 in.) apart, so that the air would discharge perpendicularly to the longitudinal axis of the duct.

Velocity profile was measured with the slot oriented vertically. Linear velocity was measured with a hot wire anemometer for three vertical levels at three downstream locations from the slot. Figure 3 shows the measured velocity profile. As can be seen the velocity distributions for the three vertical levels are virtually identical. Therefore, the air curtain flow field is uniform.

The air curtain flow field was measured for several slot widths and air slot exit velocities. The results were compared with the equations suggested by McElroy (1943) for a two-dimensional jet exhausting into still surroundings and jets with two-sided expansion.

Figures 4 and 5 show the measured centerline axial velocity decay and entrainment ratio, respectively. The agreement between the measured and predicted centerline velocity decay is good. The measured entrainment ratio was lower than that calculated.

The lower measured entrainment ratio could be due to a smaller inclusive jet expansion angle. The measured jet expansion angle varied between 20° and 28°, depending on air exit velocity. This is smaller than that reported by Tuve and Priester (1944) of 32 - 34° and that suggested by Hemeon (1963) of 30 - 40°.

The jet expansion angle and entrainment ratio were also measured for the first air curtain manifold (duct with drilled holes) we had tested. The jet expansion angle was 35°, which was close to Tuve and Priester results and within the range recommended by Hemeon. The measured entrainment ratio for this air curtain agrees with that calculated from theory.

Charged Spray Scrubber Study

Bench scale experiments were performed to determine the minimum water requirements, to aid the selection of spray nozzles, to study various drop charging methods to determine the effect of drop and/or particle charging on particle collection efficiency, and to verify published theories.

Figure 6 shows a sketch of the charged spray scrubber system. In order to enable us to make good measurements, it is much more elaborate than the actual SCAT will be.

The system was made in sections jointed by flanges. The scrubber was made of thin aluminum sheets and supported on PVC frames in order to permit electrical current measurements. The cross-section of the scrubber is 0.91 m x 0.91 m (3 ft x 3 ft). The overall length, including the blower, is about 11 m (36 ft).

The scrubber system consists of a flow straightening section, an inlet particle sampling section, a particle charging section, a spray section, an entrainment separator, and an outlet sampling section. It should be noted that all sections except the spray and entrainment separator section will not be included in an industrial installable SCAT system. The inclusion of the sections in the bench scale device is for the purpose of studying various combinations of components and to provide for good particle sampling and electrical measurement.

The particle charging section consisted of two rows of corona wires. Wire diameter was 0.18 mm (0.007 in.). The spacing between wires within the same row was 6.5 cm (2.5 in.). The ground electrodes were 1.3 cm (0.5 in.) diameter aluminum tubing.

The overall length of the spray section was 2.44 m (8 ft) including two spray banks. The water was charged by induction. The nozzles and water feed lines were kept at ground potential. A high voltage grid assembly was placed in front of the nozzles to charge the water drops. This arrangement not only simplified construction, by eliminating a complicated electrical isolation system, but also gave a high charge level on drops.

The scrubber was operated for four conditions:

1. Uncharged particles/neutral drops,
2. Charged particles/neutral drops,
3. Uncharged particles/charged drops, and
4. Charged particles/charged drops.

Figures 7 and 8 show the data for nozzles "A" and "B", respectively. The measured mass median drop diameter, spray angle, and discharge coefficient for nozzle "A" (hook type) was 240 µm, 100°, and 0.63, respectively. Only one spray bank was used in all experiments and nozzle pressure was maintained at 432 kPa (48 psig). One power supply was used to charge both the particles and the drops. The applied voltage was -10 kVDC. The measured charge/mass ratio was $+5.8 \times 10^{-5}$ C/g and -1.5×10^{-5} C/g for drops and particles, respectively.

As can be seen from Figures 7 and 8 the collection efficiency of the spray scrubber improves by charging either the water or the particles. Further improvement was measured when the water and particles were oppositely charged. The improvement is more with submicron particles. For particles with diameters larger than 5 µmA, charging the water and/or particles has little effect on efficiency.

The scrubber with nozzle "A" has better collection efficiency at a lower liquid/gas ratio than that with nozzle "B". A possible reason is that nozzle "A" produced finer drops.

Comparison Between Data and Theory

The model by Calvert (1970, 1975) along with the drop trajectory formula given by Giffen and Murozew (in Walton and Woolcock, 1960) and the appropriate single drop collection efficiency were used to predict the spray scrubber performance. Figure 9 shows the predicted and the measured grade penetration for the uncharged particle/neutral drop condition. As can be seen, the agreement is good.

For electrostatically augmented conditions, i.e. either one or both of particle and drops were charged, Nielsen's (1974) graph for single drop collection efficiency was used in the calculation. The results were identical to that for the uncharged condition. This means there should be no improvement in efficiency with electrostatic augmentation. This is contrary to experimental findings. The discrepancy could be due to the assumption that drops were of uniform size and carried the same amount of charge.

Collection in a vertical direction was not included in the calculations. While collection in a vertical direction is negligible for the uncharged particle/uncharged drop condition, it could contribute to particle collection for the charged system due to the low relative velocity between the drops and the particles.

Prototype SCAT Scrubber

A prototype SCAT system was designed and built based on the information generated in air curtain and spray scrubber studies. Its configuration is similar to that shown in Figure 1. It had two separate sections. One section housed the charged spray scrubber; the other section had three air curtains and one air push jet. Both sections were mounted on casters; therefore, the distance between the air curtains and the spray scrubber could be adjusted.

The charged spray scrubber had a cross-section of 2.44 m x 1.83 m (8 ft x 6 ft). The bottom 0.61 m (2 ft) was the scrubber sump. Therefore, the active scrubber was made of aluminum plates.

There were 36 pigtail type spray nozzles at the scrubber front surface. The sprays are cocurrent with the gas flow. The capacity of each spray nozzle is 9.8 ℓ/min (2.6 GPM) at a nozzle pressure of 377 kPa (40 psig). The nozzle discharge coefficient is 0.6 and the drop diameter is 200-250 μm.

About 1 m downstream from the sprays were four rows of zigzag baffles to remove the water drops. There was a blower at the scrubber outlet. The blower is rated at 963 m^3/min at 2.5 cm W.C. pressure drop (34,000 CFM at 1 in. W.C.).

The other section had three independent air curtains and a propeller fan. Two of the air curtains were mounted vertically and about 1.83 m (6 ft) apart. The other curtain was mounted horizontally 2.7 m (9 ft) above the ground. The air curtains could be swivelled as needed to deflect crosswinds and contain buoyant smoke plumes. The propeller fan was located at the center. The fan was for producing a "push" jet.

The prototype SCAT system was used in crosswind, hot source, and containment efficiency measurements.

Hot Source Experiments

We are conducting experiments on the prototype SCAT system operating on a simulated FPE hot source. Figure 10 illustrates the test setup. A furnace is used to generate a hot buoyant plume. Smoke is injected in the plume as a tracer. We will monitor the air curtain angle, flow rate, and slot geometry required to divert the hot plume into the scrubber. No data are yet available.

Application of SCAT Scrubbing on Street Sweepers

As an application of the SCAT approach, Air Pollution Technology, Inc. (A.P.T.) has undertaken a program to develop a special purpose street sweeper. At present street sweepers are not designed to collect inhalable particles dispersed during street cleaning.

The objective of the study is to retrofit existing vacuum sweepers with an air pollution control system to collect 90 percent of the inhalable particles dispersed by the sweeper.

The study is divided into two phases. Phase I includes a theoretical and experimental study to define and verify estimates of power and water requirements as well as cost and performance of the add-on system. In Phase II a conventional vacuum sweeper will be modified and evaluated under various street conditions.

A.P.T. will modify a regenerative air type vacuum sweeper to collect inhalable particles dispersed during street sweeping. A schematic diagram of the sweeper operation is given in Figure 11. The gutterbroom transfers the dirt from the curb to the pick-up head. Air flow in the pick-up head conveys the dirt to the hopper where the coarse particles are removed. The air is then recirculated to the pick-up head. The two sources of fine dust dispersion are the gutterbroom and the pick-up head. Dust dispersed by the gutterbroom will be conveyed to the spray scrubber and collected. Further, a stream of air will be exhausted from the system to ensure a positive intake of air at the pick-up head. This will reduce air "spills" created by the air in the head. Inhalable particles will be removed from the air stream before exhausting it into the atmosphere. Fine water sprays will be used to collect and agglomerate suspended dust particles. Either the drops or the particles (or both) may be electrostatically charged to increase the particle collection efficiency. The dust collection system will consist of a charger and water sprays followed by an entrainment separator.

The primary design constraints for this system are:

1. Minimize water usage,
2. Maximize collection efficiency for inhalable particles through electrostatic augmentation,
3. Optimize entrainment separator to collect drops and coarse particles, and
4. Minimize power required for air recirculation.

Conclusions

The SCAT system is a simple, versatile and effective technique for controlling fugitive emissions. It involves the use of air curtains and air jets to contain and convey the emissions into a nearby spray scrubber.

The collection efficiency of a single spray bank scrubber was investigated experimentally. The collection efficiency could be improved by charging the water and/or the particles. The measured particle penetration agrees with theoretical predictions. For charged water and/or charged particle condition, the measured penetration is lower than the predicted.

Air curtains have been used in industries to contain dust but no carefully performed study has been reported in the literature. The air curtain developed in the present study can achieve a smaller expansion angle and a lower entrainment ratio than those reported in the literature. Small expansion angle and entrainment ratio are beneficial to the control of fugitive process emissions with the SCAT system.

A prototype SCAT system has been built by A.P.T. to study the effects of crosswind, hot buoyant plume, and containment efficiency. Experiments are currently underway.

The SCAT concept is also being applied to urban street sweepers to improve their effectiveness in controlling emissions of inhalable particles from paved streets. Preliminary analysis indicates that the system is very promising and can have a significant impact on urban air quality.

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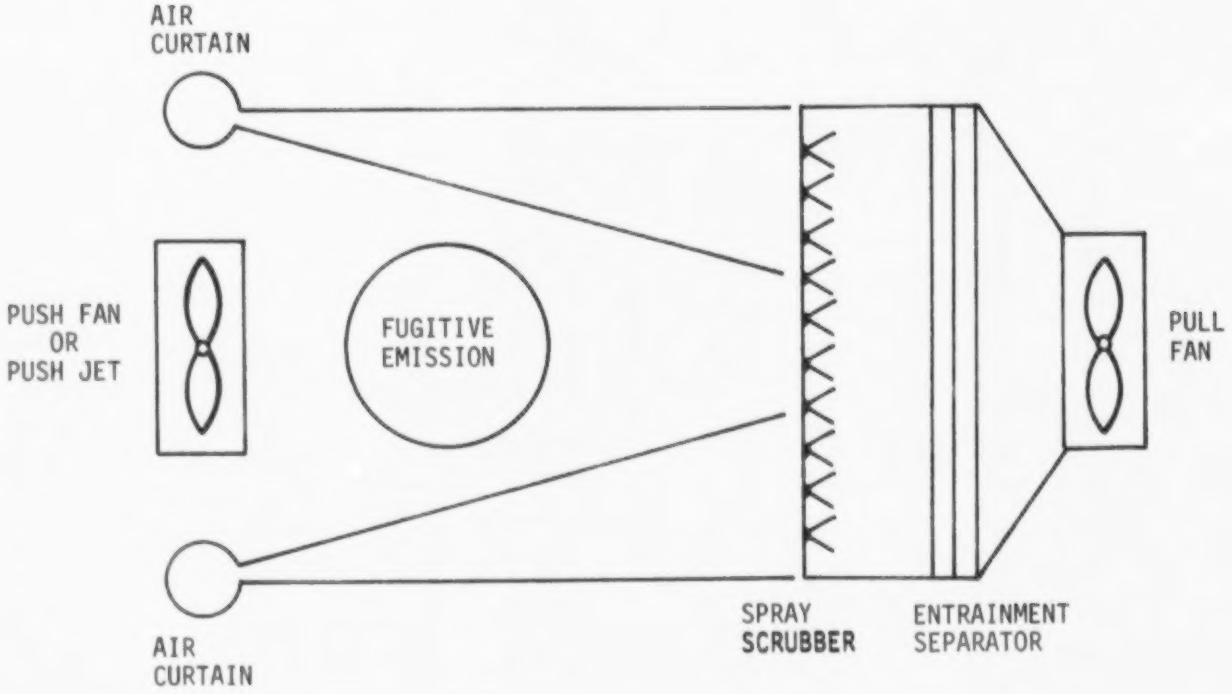
AIR
CURTAIN
PUSH FAN
OR
PUSH JET
FUGITIVE
EMISSION
AIR
CURTAIN
SPRAY
SCRUBBER
ENTRAINMENT
SEPARATOR
PULL
FAN

Figure 1. Example of SCAT system arrangement.

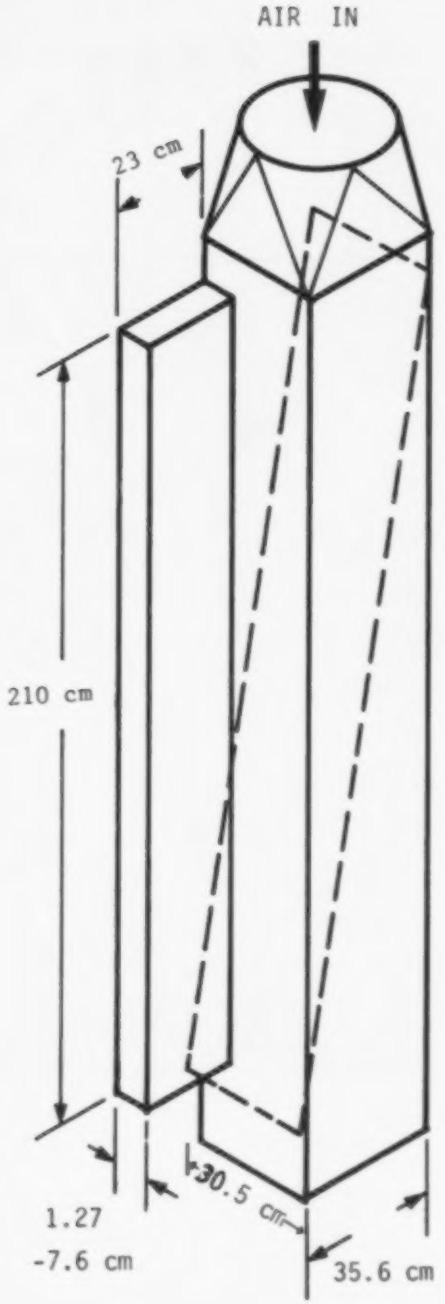
AIR IN
23 cm
210 cm
1.27
-7.6 cm
30.5 cm
35.6 cm

Figure 2. Air curtain distribution duct.

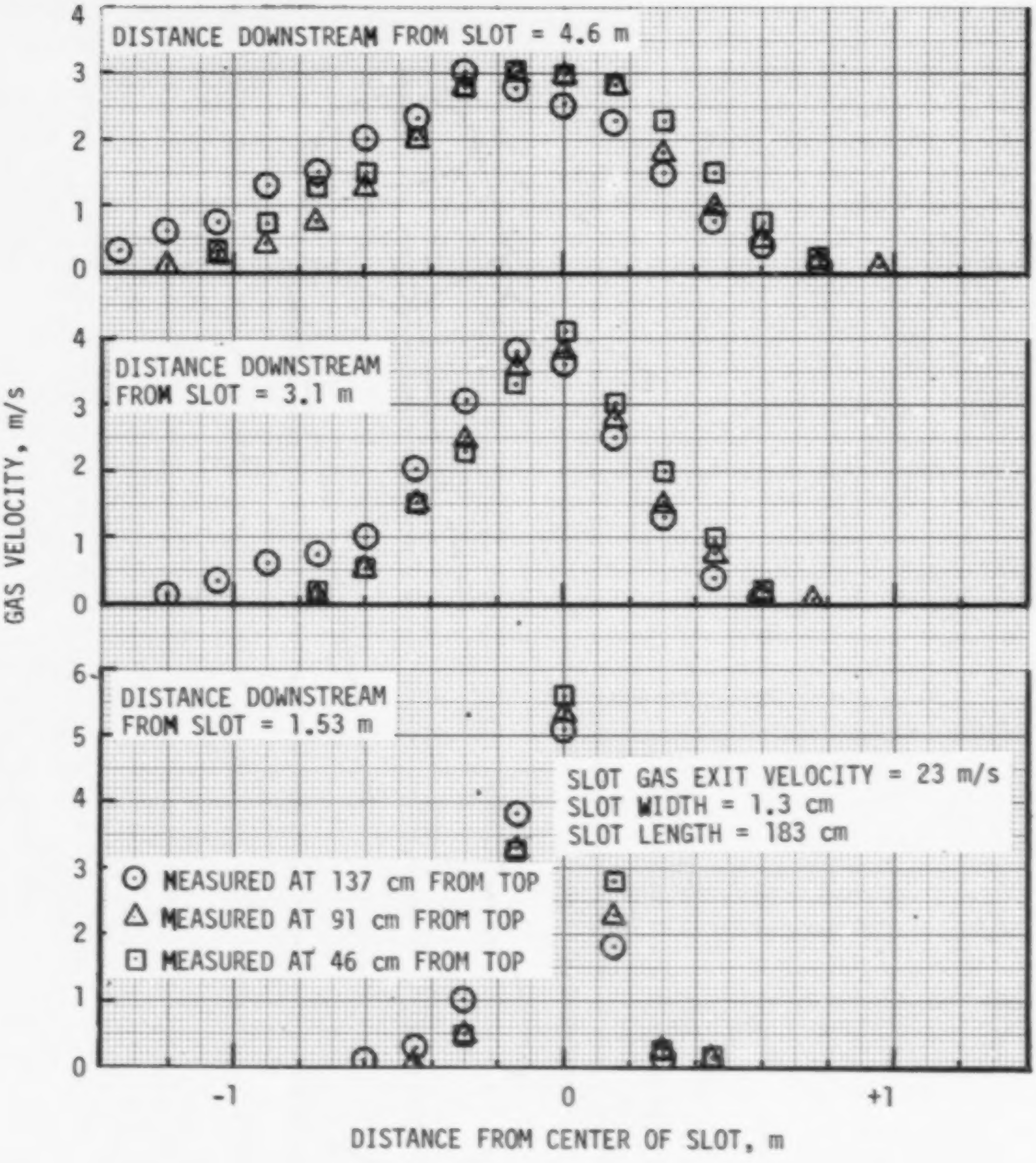

Figure 3. Velocity profile of an air curtain.

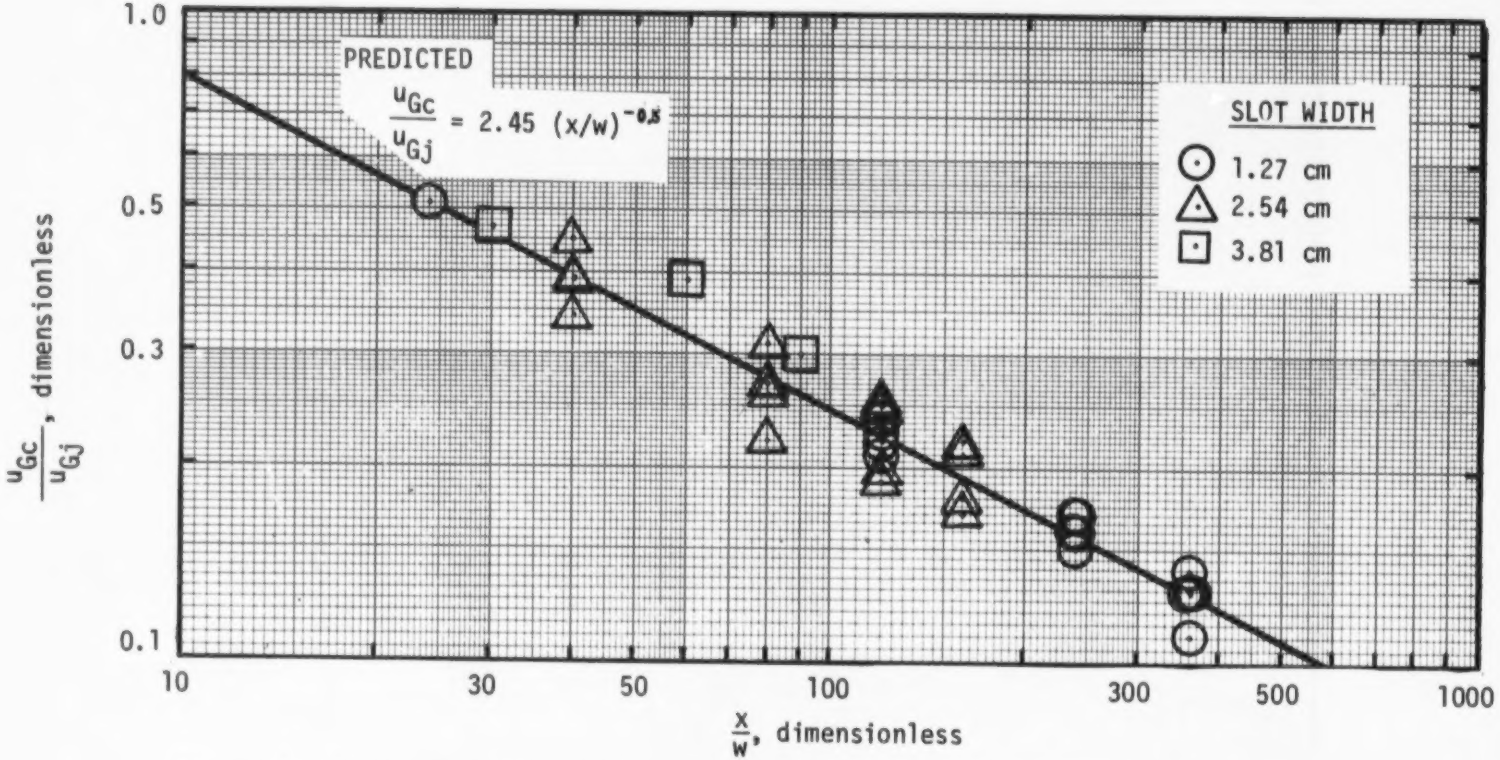

Figure 4. Measured and predicted centerline axial velocity decay.

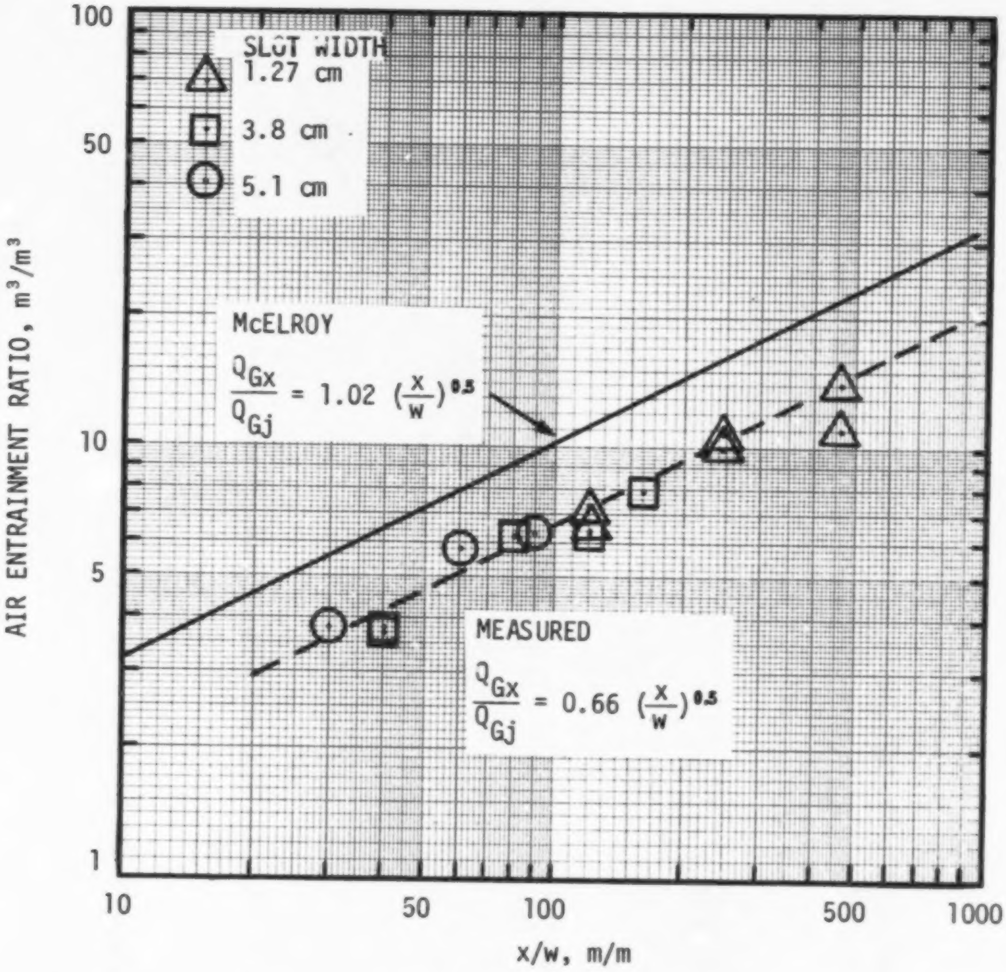

Figure 5. Measured and predicted air entrainment ratio.

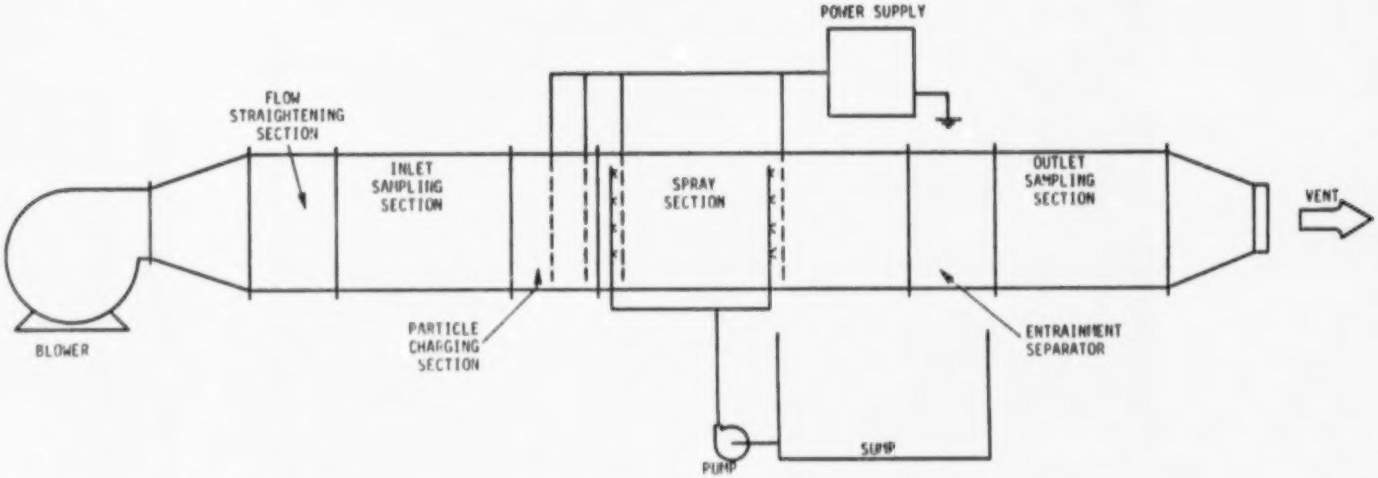
POWER SUPPLY
FLOW STRAIGHTENING SECTION
INLET SAMPLING SECTION
SPRAY SECTION
OUTLET SAMPLING SECTION
VENT
BLOWER
PARTICLE CHARGING SECTION
ENTRAINMENT SEPARATOR
PUMP
SUMP

Figure 6. Experimental apparatus for studying charged spray section of SCAT scrubber.

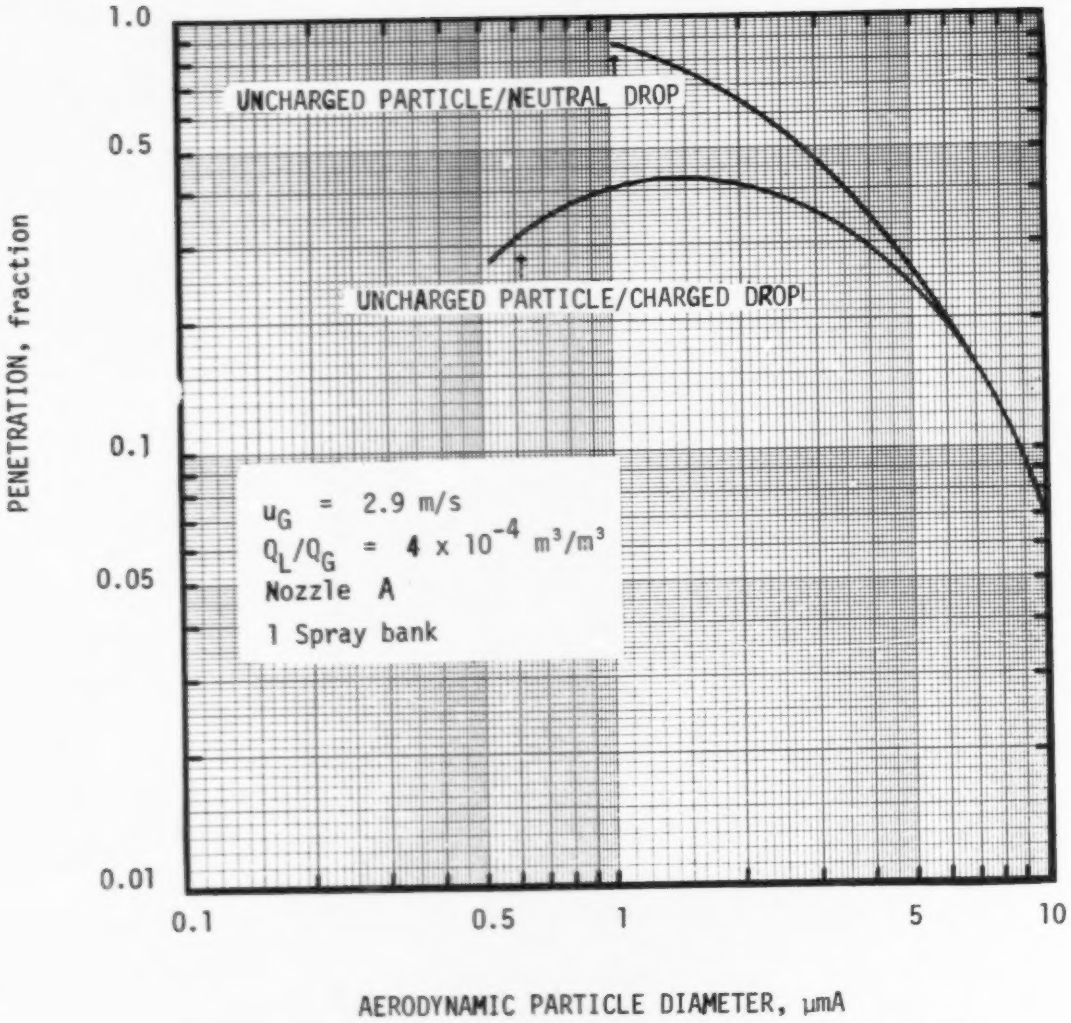

Figure 7. Measured spray scrubber penetration, nozzle A.

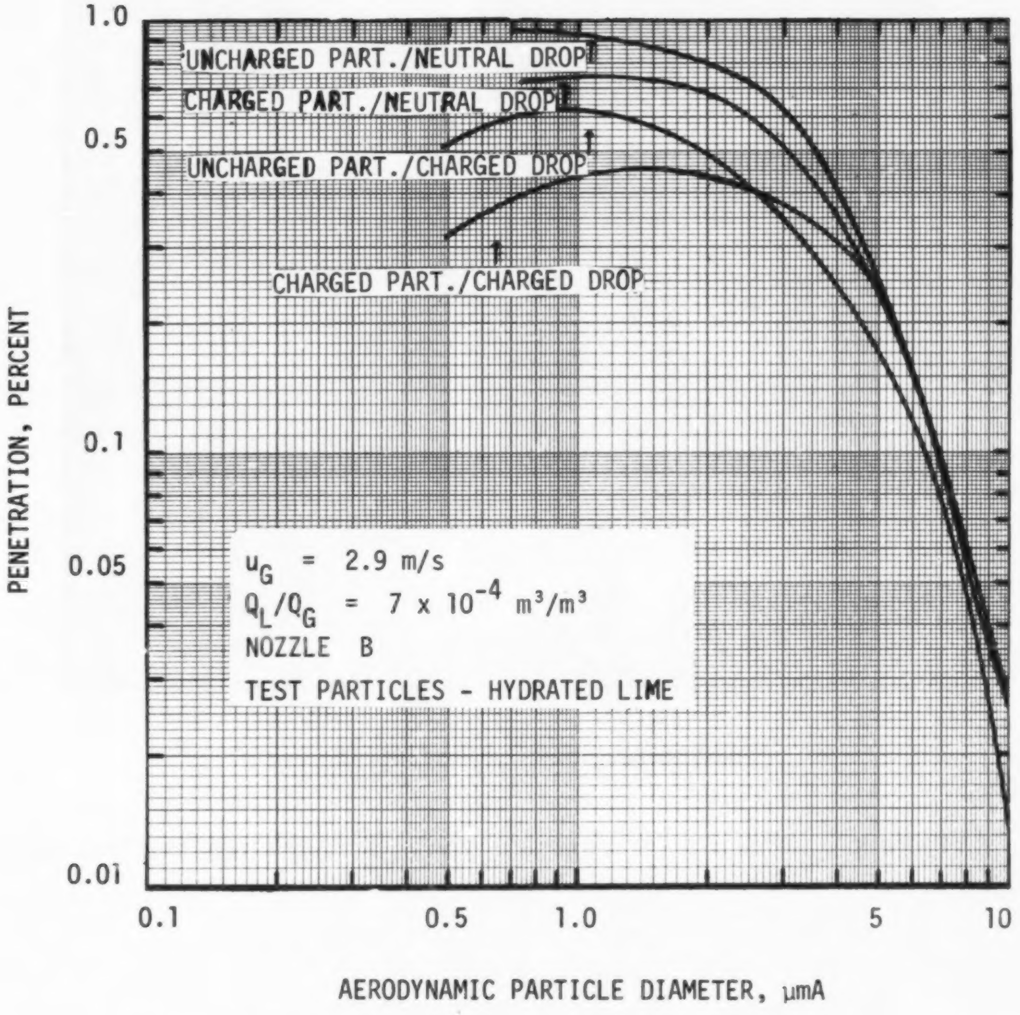

Figure 8. Measured SCAT spray scrubber performance, nozzle B.

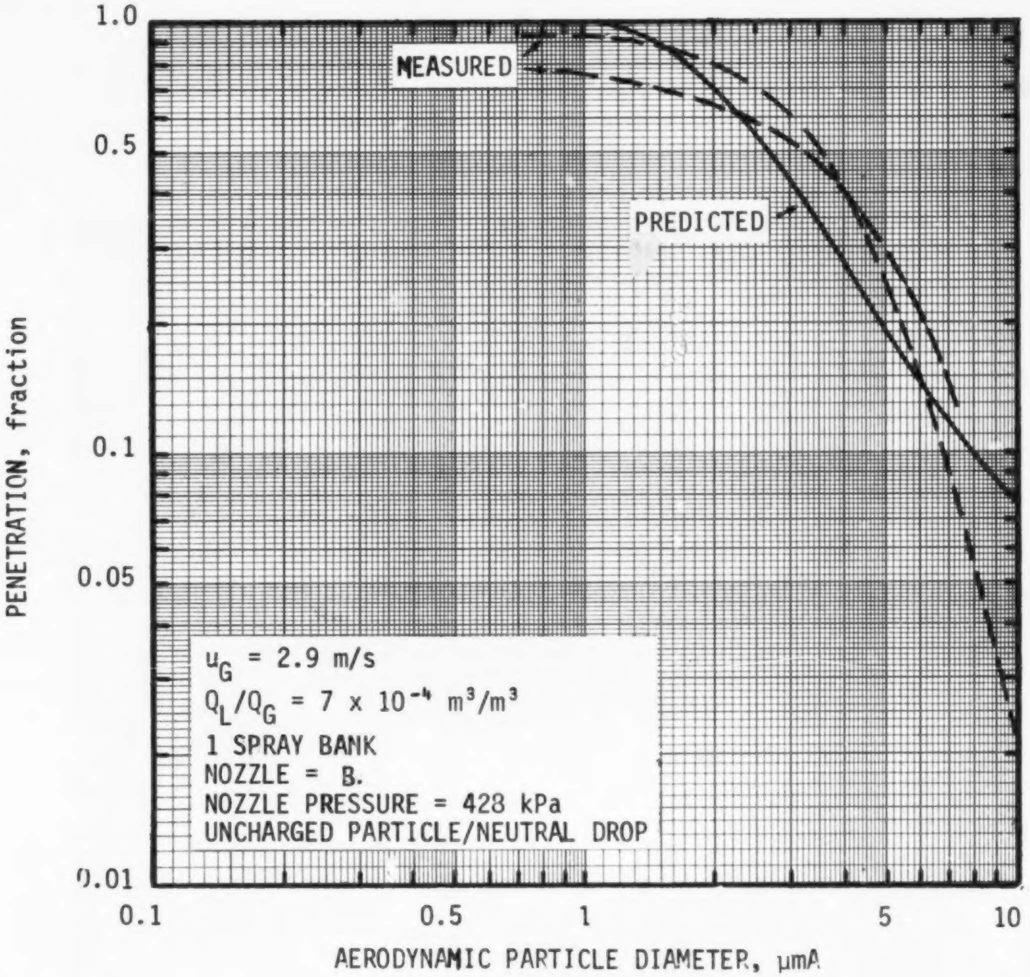

Figure 9 . Predicted and measured spray scrubber penetration, nozzle B.

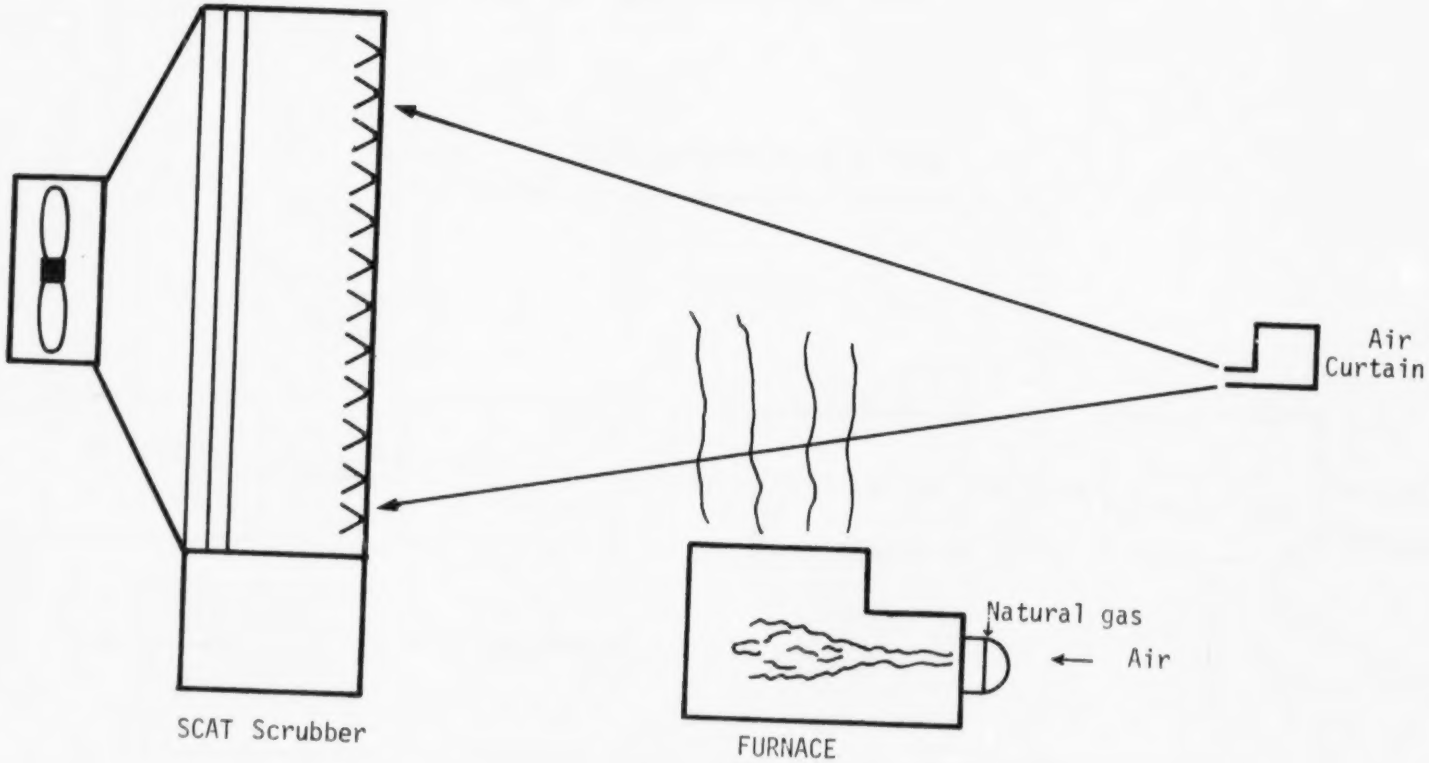
Air
Curtain
Natural gas
Air
SCAT Scrubber
FURNACE

Figure 10. Hot source experiment.

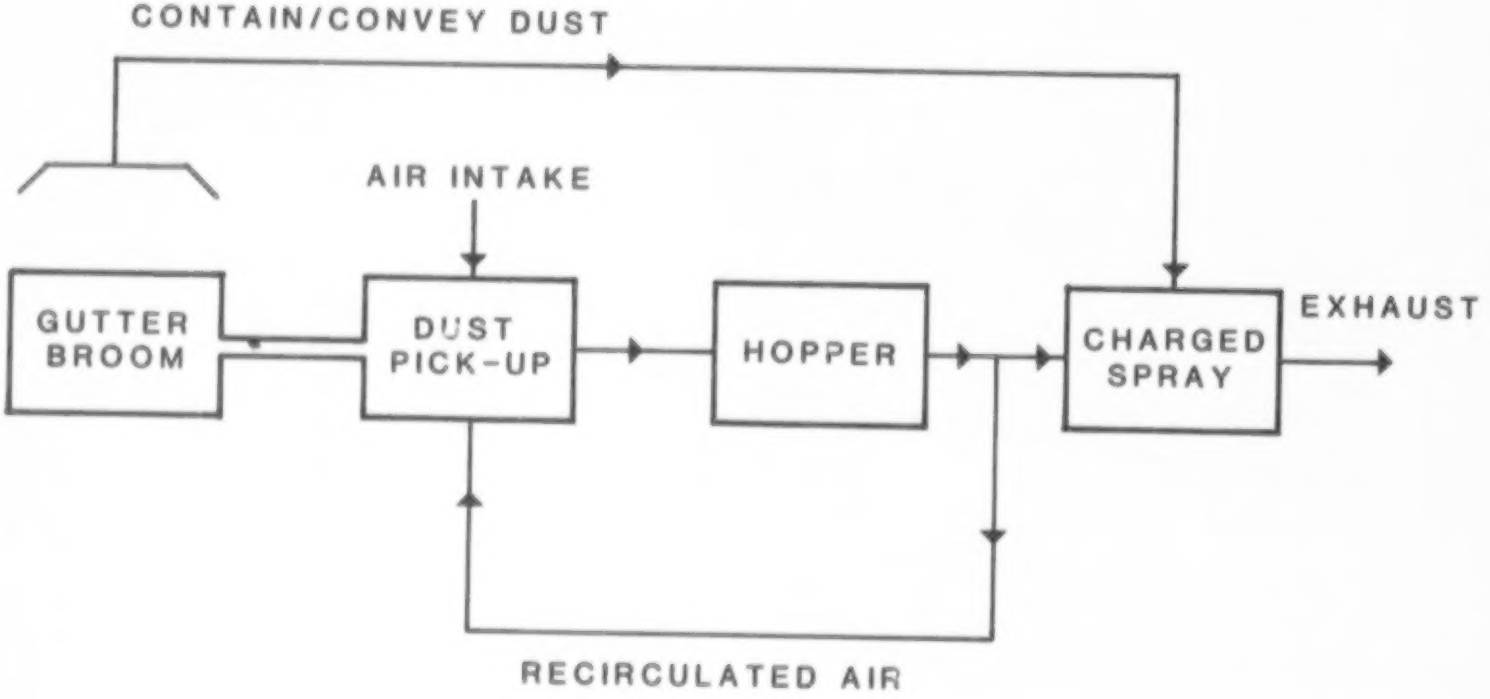
CONTAIN/CONVEY DUST
AIR INTAKE
GUTTER BROOM
DUST PICK-UP
HOPPER
CHARGED SPRAY
EXHAUST
RECIRCULATED AIR

FIGURE 11. Improved Street Sweeper

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